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## THESIS

**DEVELOPMENT AND VERIFICATION OF AN  
AERODYNAMIC MODEL FOR THE NPS FROG UAV  
USING THE CMARC PANEL CODE SOFTWARE SUITE**

by

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September 1998

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THE NPS FROG UAV USING THE CMARC PANEL CODE SOFTWARE SUITE**

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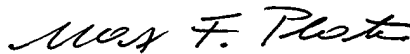
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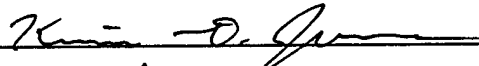


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## ABSTRACT

The CMARC panel-code is evaluated for the development of an aerodynamic model of the Naval Postgraduate School FROG Unmanned Air Vehicle (UAV). CMARC is a personal computer hosted panel-code software suite for solving inviscid, incompressible flow over complex three-dimensional bodies. A panel model of the NPS FROG UAV is developed to obtain stability derivative data at the cruise flight condition. Emphasis is placed on comparing the CMARC data to aerodynamic models obtained from classical design techniques and parameter estimation. Linearized longitudinal and lateral-directional state-equation models are used to compare the dynamic response of each data set. In addition, CMARC is used to generate static-source and angle-of-attack sensor position corrections. Position corrections are provided in look-up table and curve-fit formats. The aerodynamic model obtained with CMARC demonstrated higher fidelity dynamic longitudinal response than the classical design model. Dynamic lateral-directional response is similar to that obtained from classical design techniques. Adjustment through comparison with flight-test data is still required to optimize the CMARC model. Future studies should concentrate on improving CMARC modeling of fuselage side force through the addition of wake separation lines. Additionally, the propeller disk should be modeled in an attempt to capture the effects of increased dynamic pressure over the horizontal and vertical tail surfaces.



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## I. INTRODUCTION

### A. BACKGROUND

Computational fluid dynamics (CFD) is increasingly used as a design and analysis tool. As the price of computer hardware drops and computational power increases, CFD becomes more attractive to a larger audience. CFD tools range from the high-end three-dimensional (3D) Navier-Stokes solvers for compressible, viscous fluids to potential flow solvers for incompressible, inviscid flows. This paper discusses the development of an aerodynamic model of the Naval Postgraduate School (NPS) Fiber Optic Guided (FROG) Unmanned Air Vehicle (UAV) using a personal computer hosted panel code.

Validation of the Personal Simulation Works panel code software and initial FROG UAV modeling was completed in June 1997. Results are reported in Ref. [1]. This study expands on the modeling effort to include the development of a complete aerodynamic model at the trim flight condition. Stability derivative data are obtained from the panel code and then compared to data from classical design calculations and parameter estimation. A linearized state space simulation is used to extract the air vehicle dynamic modes and to model control response. Results are compared for all three data sets.

The Personal Simulation Works software suite, consisting of LOFTSMAN, CMARC and POSTMARC, is used for all aspects of the study. The software provides for panel model development, input file processing and the visualization of results. Emphasis is placed on verifying both the accuracy and suitability of the CFD programs for aerodynamic modeling.

Until recently, personal computers (PC) did not have the computational power or memory to be practical for panel code CFD programs. Things have changed with the introduction of the Pentium class PC and low cost RAM. AeroLogic capitalized on the power of the Pentium class PC and developed Personal Simulation Works (PSW). PSW is based on the 3D, low order, inviscid potential flow solver named CMARC. CMARC is a re-hosted version of NASA's Panel Method Ames Research Center (PMARC). PMARC was re-written in the C language and compiled for IBM compatible PCs. CMARC runs under the DOS operating system. It will also run in a DOS window under the WINDOWS 3.x, 95 or NT operating systems. Enhanced capabilities include; improved memory management, an expanded set of command line switches and

provisions for expanded boundary layer post-processing capabilities. However, the core processing algorithms remain the same as implemented in PMARC.

LOFTSMAN, the PSW pre-processing program, is used to mesh complex 3D bodies and create input file patches. The program runs under the Windows operating system and allows the user to loft conics based 3D surfaces. The program automatically creates CMARC, PMARC or VSAERO input patches based on desired panel densities and distribution.

POSTMARC is used for flow visualization and integration of resultant forces. It runs under the Windows 3.x, 95 and NT operating systems. POSTMARC reads CMARC or PMARC output files and provides for the visualization of model geometry, wake stepping, on and off-body streamlines and surface phenomena.

## **B. REQUIREMENTS**

The Naval Postgraduate School Aeronautics Department is integrating UAV hardware and software to demonstrate autonomous flight, trajectory tracking and automatic landing. Closed-loop flight control development requires a valid aerodynamic truth model for the UAV airframe. The introduction of each new airframe requires the development of a new aerodynamic truth model. Most recently, Papageorgiou [Ref. 2] developed and tested an aerodynamic model for the NPS FROG UAV based on classical methods. His model produced a close match to flight test results in the longitudinal axis. However, the lateral-directional axis required modifications based on measured flight test data to produce acceptable results. With the availability of low cost panel code CFD capabilities, it is suggested that a panel code model of the FROG UAV will provide more refined stability derivative data for an initial aerodynamic model.

In addition to a valid truth model, accurate pitot-static and angle-of-attack sensors are required for highly augmented flight control systems. CMARC is well suited for solving on-body static pressure distributions and off-body flow velocities over the predominately attached flow fields of a fuselage forebody. This proves particularly useful for generating pitot-static and angle of attack correction curves and look-up tables.

## **C. STATEMENT OF OBJECTIVES**

The Naval Postgraduate School Aeronautics Department has both active CFD research and avionics development programs. The primary purpose of this investigation

is to verify the accuracy and suitability of the PSW software suite for developing an aerodynamic model of the NPS FROG UAV. Specific objectives are as follows:

- Demonstrate panel code modeling, processing and visualization on a Pentium PC using the PSW software package.
- Develop and analyze a panel code model for the NPS FROG UAV using PSW to obtain a complete set of stability derivatives at the cruise trim condition.
- Verify the aerodynamic model through comparison to data obtained from classical design calculations and parameter estimation.
- Demonstrate techniques for producing angle-of-attack vane and pitot-static correction curves.
- Develop a user guide that outlines PSW panel code modeling for the extraction of stability derivatives.



## **II. OVERVIEW OF PERSONAL SIMULATION WORKS**

### **A. GENERAL**

Personal Simulation Works is a PC based software suite that provides for the three primary CFD requirements; 3D modeling of an aircraft (LOFTSMAN), panel code flow solver (CMARC), and post-processing of the computed flow field (POSTMARC). The software package contains three applications hosted on the IBM compatible personal computer. Each software program is discussed separately.

### **B. LOFTSMAN**

LOFTSMAN is a Windows hosted 3D modeling tool that generates surface panel distributions for CMARC or PMARC input files. The program is based on conics, which allows rapid lofting of streamlined bodies such as aircraft fuselages and engine nacelles. In addition, wing and control surfaces can be designed with the extensive library of airfoil templates or with user specified coordinates. The software is well documented, including a tutorial, in the Personal Simulation Works User Guide [Ref. 3]. LOFTSMAN is primarily designed for creating new objects, but an existing airframe can be matched quite closely with just a detailed three-view drawing that includes frame cross sections. Appendix A outlines the development of the FROG UAV model.

#### **1. Streamlined Bodies**

LOFTSMAN functionality is divided into Body Objects and Wing Objects. In general, they remain separate unless the intersection between a wing and body is required.

Body Objects are created using a family of curves called second-degree conics. Circles, ellipses, parabolas and hyperbolas are among this group. An entire fuselage is described by specifying just four lines. These are the top waterline (TW), bottom waterline (BW), the maximum breadth line (MB) and the waterline of the maximum breadth line (WW). For each line, the beginning, ending and a few points along the line are specified. Control points are also specified with a curvature factor that allows LOFTSMAN to generate a smooth conic between the points. The power of conic lofting will become evident when discussing the modeling of the complex FROG UAV fuselage in Chapter V.

## **2. Wings and Control Surfaces**

Wings and control surfaces are easily specified in LOFTSMAN using a short input file created with any text editor. The file specifies root, intermediate and tip rib section, location, axis, chord and incidence. LOFTSMAN then fairs a smooth surface through the rib sections. Washout is specified by varying the incidence of the root and tip ribs. Sweep-back is controlled by staggering the tip rib location with respect to the root rib. Once the general wing surface is specified, control surfaces such as ailerons, flaps and elevators can be deflected and meshed.

## **3. Patches**

LOFTSMAN automatically meshes 3D surfaces and creates patches for CMARC/PMARC input files. The distinction between a mesh and a patch is important. A mesh is a set of quadrilateral and triangular panels that represent the surface of a wing or body. When the set of panels is organized and formatted to create a sub-component portion of a CMARC or PMARC input file, it is called a patch.

A body or wing surface is first meshed at a density specified by the user. Panel compression options include cosine and half-cosine spacing. After meshing the object, one saves it to a text file as a formatted patch. One then opens the patch file with any text editor and copies/pastes the patch text into the appropriate location in the CMARC input file.

Each control surface deflection requires a separate mesh and formatted patch. For instance, to evaluate roll performance one needs to separately mesh an upward aileron deflection on the right wing and a downward deflection on the left wing. If multiple deflections of a single control surface are required, each deflection must be meshed separately.

## **C. CMARC**

CMARC is the C version of PMARC low-order, 3D panel code. Inviscid, irrotational, incompressible, potential flow is assumed. Low-order means that source and doublet strength distribution is constant across a panel. There is no attempt to match the source or doublet strength of an adjacent panel at a common edge. Advanced features include internal flow modeling and time stepping wake models.

PMARC version 12.19 was released as FORTRAN 77 source code in 1992. CMARC was rewritten in the C language and compiled for hosting on IBM compatible personal computers by AeroLogic, Inc. The program runs under the DOS operating system. It will also run in a DOS window from Windows 3.1, 95 or NT. Enhanced features include command-line options and flexible memory management. Command line options simplify batch processing by adding an extensive set of switches that can be set external to the CMARC input file. Flexible memory management provides for the automatic sizing of arrays without having to recompile the source code.

#### **D. POSTMARC**

POSTMARC is a Windows post-processing program for the visualization of CMARC and PMARC output files. Capabilities include body geometry, wake stepping, surface pressure and streamline visualization. POSTMARC also provides the capability to integrate pressure and skin friction forces over the model geometry. This proves particularly useful when one desires to recalculate loads around a different center of gravity.

An interesting feature for design work is the integration of panel surface area to obtain total wetted area. After lofting a new geometry in LOFTSMAN, a quick check of geometry is made by running CMARC with the -g command line toggle. The total wetted area is then checked in POSTMARC. This function is particularly useful when working to reduce skin friction drag.

Versions 1.17.3 and later of POSTMARC include the capability to integrate skin friction drag coefficient over the model geometry. It is important to note that a key piece of the drag equation is missing from a POSTMARC solution. CMARC provides induced drag from the surface pressure distribution and skin friction drag from the 2D boundary layer code. Skin friction is only calculated up to the point of boundary layer separation. Pressure drag due to separation, a major portion of the drag equation, is missing from a CMARC/POSTMARC solution.

In fact, if one isn't careful, POSTMARC drag calculations can be misleading. Take for instance two similar model configurations with only minor geometry differences that do not affect wetted area. It is possible for the model with more flow separation to have less skin friction drag because there is no CMARC output for skin friction coefficient after the boundary layer code predicts separation. During iterative design

work, this could lead to the incorrect conclusion that the design team is reducing overall drag. Perhaps a better function for LOFTSMAN than integrated skin friction drag would be a function that predicts the percentage of attached flow and laminar flow. Iterative design changes could be made that maximize laminar flow and minimize separated flow.

### III. CMARC PANEL CODE THEORY

#### A. POTENTIAL FLOW PANEL CODE THEORY (CMARC/PMARC)

Potential flow theory involves the superposition of sources and doublets to generate the desired flow field around a 3D body. It assumes inviscid, irrotational and incompressible flow. As such, valid solutions are only obtained at low Mach numbers and for flow fields without large areas of separation.

The basic concept of panel methods, as outlined by Bertin and Smith [Ref. 4], requires the modeling of the desired 3D configuration with a large number of quadrilateral and triangular panels representing the surface of the aircraft. A series of sources, doublets and vortices is then distributed on each panel. Superposition allows the simultaneous computation of the singularity strengths required to satisfy flow tangency on the surface. The inviscid, irrotational and incompressible flow field represented by the superposition of sources and doublets satisfies the Laplace equation:

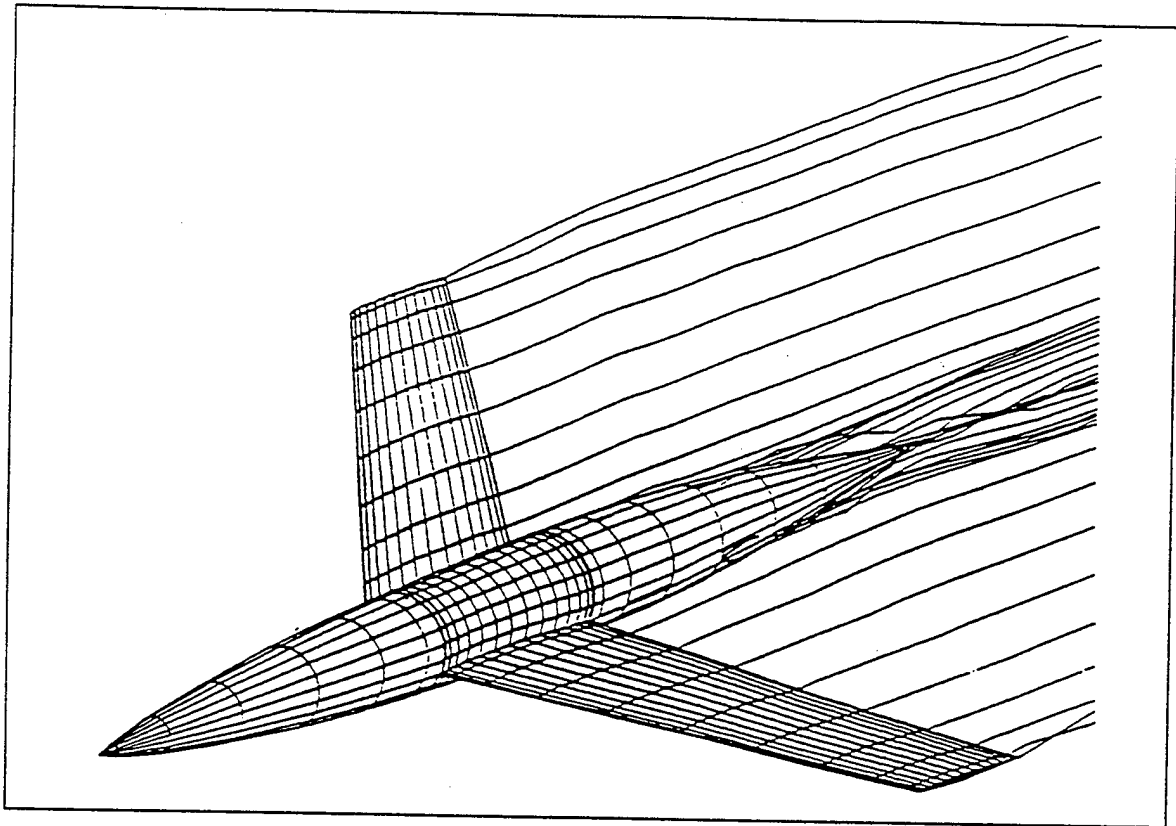
$$\nabla^2 \Phi = 0 \quad 3.1$$

Using Green's Theorem, the potential at any point P in the flow is represented by:

$$\Phi_P = \frac{1}{4\pi} \iint_{S+W} (\Phi - \Phi_i) \bar{n} \nabla \left( \frac{1}{r} \right) dS - \frac{1}{4\pi} \iint_{S+W} \left( \frac{1}{r} \right) \bar{n} \cdot (\nabla \Phi - \nabla \Phi_i) dS \quad 3.2$$

Where  $(\Phi - \Phi_i)$  represents the potential from the doublet distribution and  $\bar{n} \cdot (\nabla \Phi - \nabla \Phi_i)$  represents the potential from the source distributions.

CMARC is a low order panel code that assumes constant source and doublet strength distributions across each panel. Figure 3.1 shows a panel layout for a generic 3D wing fuselage configuration. It is important to note that for a 3D solution, there is an equivalence to surface doublet and surface vortex distributions. CMARC implements source and doublet distributions.



**Figure 3.1 Typical Wing/Body Panel Code Configuration, from Ref. [5].**

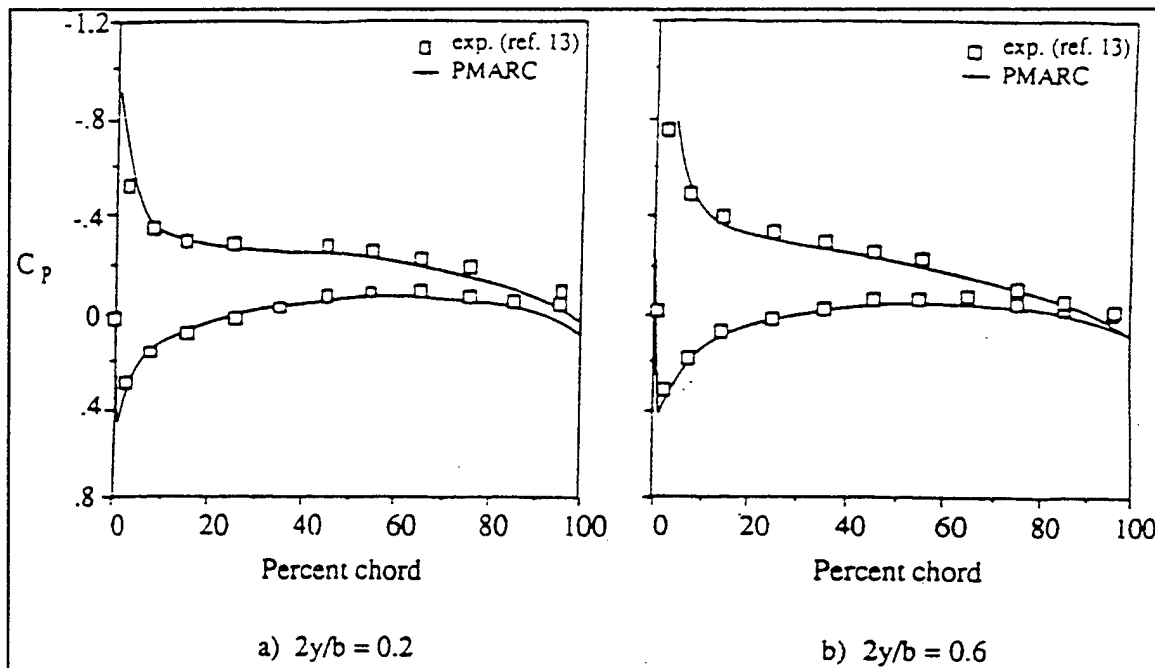
As mentioned previously, the general boundary condition imposed is tangential flow at the surface. CMARC, as outlined in Ref. [3], allows the modification of this boundary condition on individual panels or groups of panels. A normal surface velocity distribution may be specified to simulate flow into or out of ducts.

In order to produce lift, a potential flow panel code requires a method to implement the Kutta condition. As noted in Anderson [Ref. 6], the Kutta condition at the trailing edge implies that the circulation,  $\Gamma$ , around an airfoil is such that the flow exits the trailing edge smoothly. In addition, the velocities leaving the top and bottom surfaces are finite and equal in magnitude and direction.

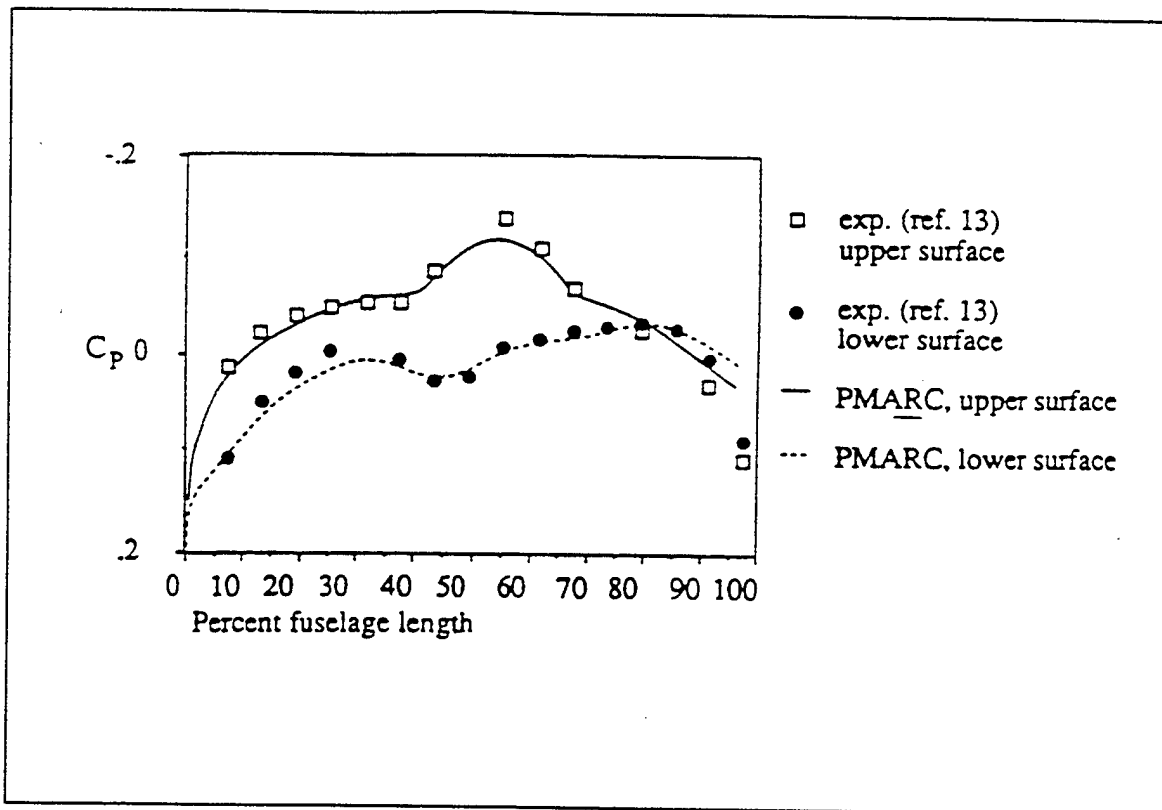
Panel codes impose the Kutta condition by the shedding of wake panels along the trailing edges or separation lines. Wake panels are similar to a surface panel with only a doublet distribution. The doublet strength of the attached wake panel equals the difference in doublet strengths of the two adjacent surface panels.

The CMARC core panel code processing engine is functionally equivalent to the PMARC panel code module. The implemented equations are well documented by Ashby et al. [Ref. 5]. The PMARC documentation includes a wing-body combination, shown in Figure 3.1, evaluated by PMARC with good correlation to experimental data. The results are shown in Figures 3.2 and 3.3. In addition, Lambert [Ref. 7] compared PMARC panel code results to several theoretical and experimental test cases with good correlation at low angle-of-attack. Sensitivity to wake placement is highlighted by his studies.

Wake positioning can have a large influence on potential flow solutions. A wake is obviously attached to the trailing edge of wings and control surfaces with sharp, thin trailing edges to produce the Kutta condition. However, wake positioning on streamlined fuselages, missile airframes and nacelles is more of an art than science. Recently, Tuncer and Platzer [Ref. 8] investigated generalized wake placement techniques for cylindrical bodies of revolution with good correlation to experimental data at up to 20 degrees angle-of-attack. The techniques were used with success by this author in Ref. [1] for the verification of CMARC calculations for flow over an inclined 6:1 prolate spheroid.



**Figure 3.2 Comparison of Experimental Data and PMARC Results for Two Spanwise Stations of the Wing/Body ( $\alpha = 4^\circ$ ), from Ref. [5].**



**Figure 3.3 Comparison of Experimental Data and PMARC Along the Fuselage Centerline of the Wing/Body Configuration ( $\alpha = 4^\circ$ ), from Ref. [5].**

## **B. CMARC BOUNDARY LAYER ANALYSIS THEORY**

CMARC and PMARC use the same two-dimensional integral method to calculate boundary layer characteristics along a surface streamline. A transition model automatically switches from laminar to turbulent calculations. The developers of the PMARC code chose a 2D integral routine over a 3D finite difference grid method due to speed and robustness of the calculations [Ref. 5]. Building a finite difference grid is a difficult and time consuming process requiring the user to develop grids over complex 3D surfaces. In addition, boundary layer calculation times can easily exceed that required for the basic potential flow solution. Reference [9] gives a good outline of three-dimensional finite difference methods.

The CMARC and PMARC User's Guides [Refs. 3 and 5] contain detailed discussions on the development of the CMARC/PMARC boundary layer code starting from the two-dimensional momentum equation:

$$\frac{d\theta}{d\eta} + (2 + H) \frac{\theta}{U} \frac{dU}{d\eta} = \frac{1}{2} C_f \quad 3.3$$

The momentum integral equation is numerically integrated along a surface streamline.

The laminar region of the boundary layer is modeled by numerically integrating the following exact differential equation. The equation is solved iteratively through numerical integration along a streamline starting at a stagnation point [Ref. 5]:

$$\theta(\eta)^2 = \frac{0.45\nu}{U(\eta)^6} \int_0^\eta (1 + 2.222g(K, \mu)) U(\eta)^5 d\eta + \theta(0)^2 \left( \frac{U(0)}{U(\mu)} \right)^6 \quad 3.4$$

where: U - velocity at outer edge of boundary layer  
 $\theta$  - momentum thickness  
 $K = \frac{\theta^2}{\nu} \frac{dU}{d\eta}$   
 $\eta$  - generalized coordinate along a streamline

The value  $g(K, u)$  is based on exact solutions for a number of pressure distributions. Initial work was conducted by Thwaites with improvements by Curle [Ref. 10]:

$$g(K, \mu) = F_0(K) - \mu G_0(K) - 0.45 + 6K \quad 3.5$$

CMARC uses an empirical transition model based on the average pressure gradient,  $\bar{K}$ , for predicting laminar to turbulent transition. The following relations are used to calculate the transition point [Ref. 5]:

$$\bar{K} = \frac{\int_{\eta_{ins}}^{\eta} K d\eta}{\eta - \eta_{ins}} \quad 3.6$$

where  $\eta_{ins}$  is the streamline coordinate at instability. And, K is the local pressure gradient at boundary layer instability [Ref. 5]:

$$\begin{aligned} K &= -0.4709 + 0.11066 * \ln(\text{Re}_\theta) + 0.0058591 * \ln^2(\text{Re}_\theta) & (0 \leq \text{Re}_\theta \leq 650) \\ K &= 0.69412 - 0.23992 * \ln(\text{Re}_\theta) + 0.0205 * \ln^2(\text{Re}_\theta) & (650 < \text{Re}_\theta \leq 10000) \end{aligned} \quad 3.7$$

The local Reynolds number at transition is correlated to  $\bar{K}$  with the following expressions [Ref. 5]:

$$\begin{aligned} \bar{K} &= -0.0925 + 0.00007 * \text{Re}_\theta & (0 \leq \text{Re}_\theta \leq 750) \\ \bar{K} &= -0.12571 + 0.000114286 * \text{Re}_\theta & (750 < \text{Re}_\theta \leq 1100) \\ \bar{K} &= 1.59381 - 0.45543 * \ln(\text{Re}_\theta) + 0.032534 * \ln^2(\text{Re}_\theta) & (1100 < \text{Re}_\theta \leq 3000) \end{aligned} \quad 3.8$$

At transition, the initial turbulent shape factor, H, is given by the following empirical formula that is a fit to data developed by Coles [Ref. 10]:

$$H = \frac{1.4754}{\log_{10}(\text{Re}_\theta)} + 0.9698 \quad 3.9$$

Provisions are made to check for turbulent reattachment if laminar separation is encountered. At laminar separation, a point calculation is made to determine if the boundary layer will reattach. If reattachment is predicted, the boundary layer code immediately switches to turbulent calculations. No attempt is made to model the laminar separation bubble or provide a transition length. After laminar separation is predicted, the following empirical relations are used to determine if reattachment occurs [Ref. 5]:

$$\begin{aligned}
 K &= 0.0227 - 0.007575 * Re_{\theta} - 0.000001157 * Re_{\theta}^2 & (Re_{\theta} \geq 125) \\
 K &= -0.09 & (Re_{\theta} < 125)
 \end{aligned}
 \tag{3.10}$$

The boundary layer code in CMARC uses a point transition model. No attempt is made to model a more representative transition length. Turbulent calculations begin at transition using the Nash-Hicks model [Ref. 5]. Calculations continue along the streamline until turbulent separation is predicted or the end of the streamline is reached. No boundary layer data is available after separation.

The authors of PMARC caveat that their boundary layer calculations are quite accurate for predominately 2D flow but break down in regions of large cross flow near separation. This premise was tested in Reference [1] by comparing the predominately 2D flow over the inboard region of a high aspect ratio wing to the finite difference calculations performed by the Naval Postgraduate School Unsteady Potential Flow Code (UPOT). In general, CMARC provided correct trends for both the transition and separation points. However, in all cases, CMARC predicted early transition and late flow separation. As expected, the differences were greatest at lower Reynolds numbers where boundary layer thickness is larger.

Reference [1] also modeled flow over an inclined prolate spheroid. The 6:1 prolate spheroid was chosen because extensive experimental data is available. In addition, the three-dimensional flow around a prolate spheroid is similar to a streamlined slender fuselage. With proper wake placement, CMARC was found to produce accurate normal force and pitching moment coefficients. Over the three-dimensional body, CMARC boundary layer calculations also predicted early transition and late flow separation. Despite inaccuracies, CMARC boundary layer calculations remained useful when used as a design tool for visualizing the trend in transition and separation points with configuration changes.



## **IV. AERODYNAMIC MODEL OF THE FROG UAV**

### **A. BACKGROUND**

The Naval Postgraduate School Aeronautics Department is integrating UAV hardware and software to demonstrate autonomous flight, trajectory tracking and automatic landing. A core requirement for flight control law development is a valid aerodynamic truth model for the UAV airframe. A panel code model of the FROG UAV is one method for estimating many of the stability derivatives required for an aerodynamic truth model. This development effort concentrates on finding the static, rate damping and control power derivatives for both the longitudinal and lateral-directional axes.

Panel code modeling usefulness goes beyond the development of aerodynamic coefficients. Flight control systems require accurate pitot-static and angle-of-attack sensor inputs. CMARC accurately solves on-body static pressure distributions and off-body flow velocities over the predominately attached flow fields of fuselage fore bodies. In this study, correction curves are generated for static source and angle-of-attack probe position errors.

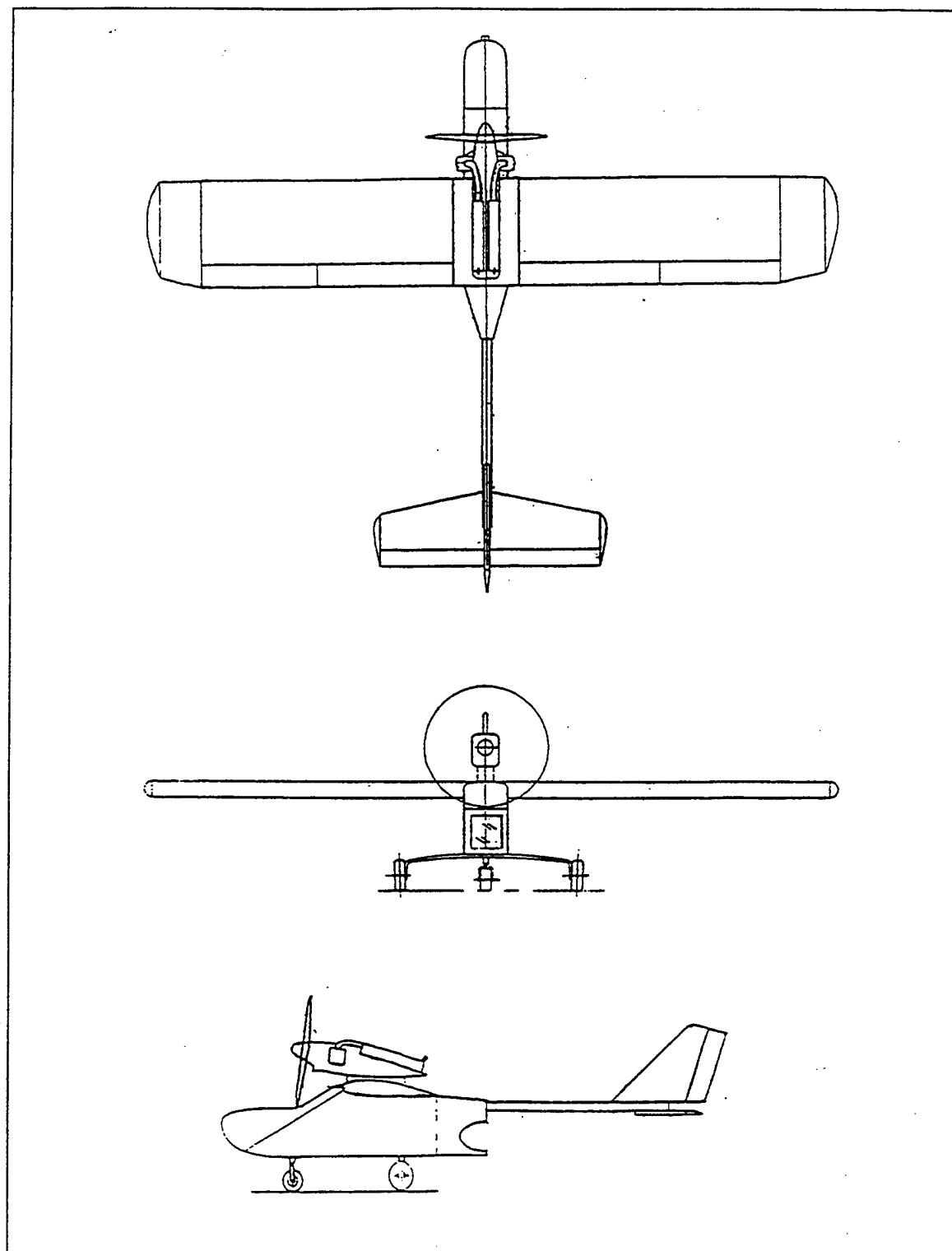
### **B. FROG UAV DESCRIPTION**

The FROG UAV is a small single engine flight test vehicle used for autonomous flight research by the Naval Postgraduate School Aeronautics Department. The aircraft was originally designated the FOG-R by the U. S. Army. It was designed as a small lightweight, battlefield observation platform that could be guided by a fiber optic data link. Table 4.1 presents the basic aircraft specifications.

The aircraft is somewhat unconventional in that the engine is mounted in a nacelle tractor style above the fuselage and wing. The aft fuselage consists of a 1.75 inch diameter aluminum tube which connects the tail surfaces to the main fuselage. Figure 4.1 displays a three view drawing of the FROG UAV.

PARAMETER	MEASUREMENT/UNITS	
Length	8.125 ft	97.5 in
Height	1.75 ft	21 in
Weight	67.7 lbs	
Power Plant	12 Hp / 2 Cycle	
Wing Airfoil	NACA 2415	
Horiz. Stab. Airfoil	NACA 0006 (Approx.)	
$S_w(S_{ref})$	17.57 ft <sup>2</sup>	2530 in <sup>2</sup>
$S_t$	3.174 ft <sup>2</sup>	457.1 in <sup>2</sup>
$S_v$	0.9818 ft <sup>2</sup>	141.4 in <sup>2</sup>
c	1.66 ft	20 in
$c_t$	0.958 ft	11.5 in
$b_w$	10.54 ft	126.5 in
$b_t$	3.313 ft	39.75 in
$b_v$	1.25 ft	15.0 in
$l_t$	4.44 ft	53.25 in
$l_v$	4.44 ft	53.25 in
$AR_w$	6.32	
$AR_t$	3.46	
$AR_v$	1.59	
$V_H$	0.49	
$V_v$	0.16	

**Table 4.1 FROG UAV Characteristics, after Ref. [2].**



**Figure 4.1 FROG UAV Three-View Drawing.**

The FROG UAV, as operated by NPS, is equipped with airspeed, angle-of-attack, altitude and control surface sensors. In addition, a miniature Inertial Measurement Unit (IMU) captures aircraft attitude, acceleration and body rates. Data is down linked to a mobile SGI workstation through a spread spectrum modem. Onboard GPS provides differential GPS navigation capability with the ground station used as a reference. The aircraft can be flown by conventional radio control or by up-linking flight control commands from the SGI workstation.

Current flight control development requires a linearized aerodynamic model around the cruise trim point of 60 m.p.h. or 88 ft/s. This flight condition is selected for the development of stability derivative data with CMARC. Table 4.2 lists the aircraft parameters for the trim flight condition.

PARAMETER	MEASUREMENT	UNITS
Weight	67.73	lbs
IXX	12.52	slug-ft <sup>2</sup>
IYY	8.43	slug-ft <sup>2</sup>
IZZ	18.55	slug-ft <sup>2</sup>
Airspeed	60/88	mph and ft/s
Altitude	800	ft MSL
Air Density	0.002327	slug/ft <sup>3</sup>
Center of Gravity	34.5%	M.A.C
$C_{L \text{ trim}}$	0.4295	n/a
$\alpha_{\text{trim (est)}}$	-0.04	degrees
$\delta_{E \text{ trim}}$	5.1	degrees

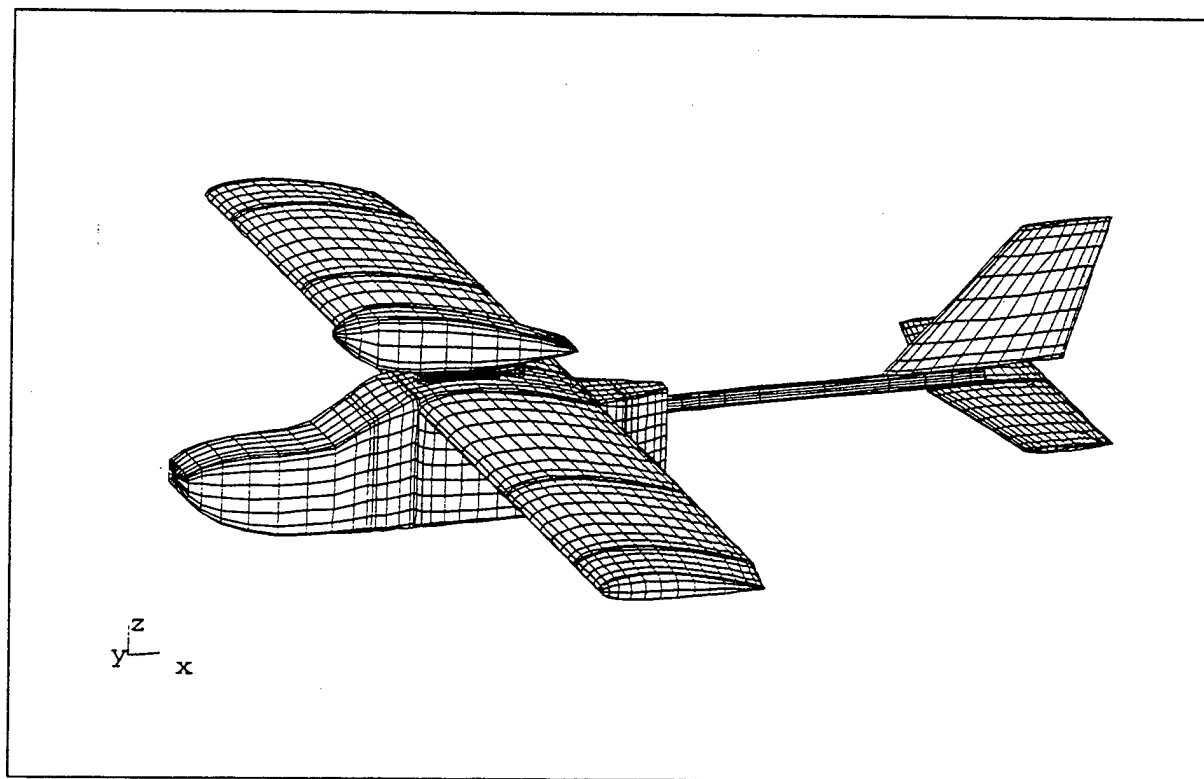
**Table 4.2 FROG UAV Trim Flight Condition, after Ref.[2].**

## **C. FROG UAV MODELING**

### **1. General**

LOFTSMAN is utilized for the creation of all CMARC input file patches except for wing tips. In some cases, CMARC's more efficient built-in capability to model standard NACA 4-digit wing surfaces could be used. However, with the requirement to mesh deflected control surfaces, all patches are created with LOFTSMAN from the start. The complete FROG UAV model with all patches activated is displayed in Figure 4.2.

Appendix A contains detailed descriptions of obtaining stability derivative data in a less formal user guide format.



**Figure 4.2 FROG UAV Panel Code Model with All Patches Activated.**

Some assumptions are made to simplify the modeling process. First, the horizontal and vertical stabilizers are modeled with a NACA 0006 section. The actual surfaces are constructed with a flat section, rounded at the nose and tapered starting at the control surface hinge line to a sharp trailing edge. The NACA 0006 provides a close approximation and allows the use of LOFTSMAN's built-in wing lofting capability. For a potential flow solution, this simplification is considered minor.

A second simplification is made regarding the vertical stabilizer's tip rib orientation. The actual rib is canted down  $5^\circ$  with respect to the longitudinal waterline. LOFTSMAN will only model a chord line that is parallel to the waterline (constant BL). Thus, for this study, the vertical tail tip rib is modeled with a constant BL, but the span is adjusted to maintain the same overall surface area.

A third assumption is made regarding aileron control surface hinge lines. The actual FROG UAV ailerons are piano hinged along the upper surface. For simplification of the LOFTSMAN model, all surfaces are hinged at the centerline.

Finally, there is no attempt to model the tricycle landing gear struts or wheel assemblies. The landing gear components do not contribute significantly to the aerodynamic stability derivatives. However, they certainly need to be taken into account when measuring moments of inertia for a dynamic model.

## **2. Modeling Coordinate System**

The model is developed using a coordinate system selected to simplify fuselage measurements. The +x-axis starts even with the nose and runs aft along the bottom of the fuselage, parallel with the tail boom. The bottom of the fuselage is used as the waterline with +z-axis in the up direction. This allows for easy vertical measurements when the aircraft is placed flat on a horizontal surface. The +y-axis runs from centerline outboard parallel to the right wing. Figure 4.3, which displays static-pressure source and alpha vane locations, also shows the location and origin of the modeling coordinate system.

## **3. LOFTSMAN Patches**

LOFTSMAN is used to generate all the model patches except for wing tips. CMARC's built-in capability is used to create wing tip patches. Appendix B contains listings of all the LOFTSMAN input files. Once a surface is meshed, the mesh is saved to a file as a CMARC/PMARC patch. The resulting text file is then opened, and the text is copied and pasted with any text editor into the patch definition section of the CMARC input file. LOFTSMAN patch files are not listed because they are redundant with the patches in the final CMARC input file listed in Appendix C. Multiple patches for the same control surface may be stored in the input file. For instance, two horizontal stabilizer patches with different elevator deflection angles may be kept in the CMARC input file. However, only one may reside in the active patch input section. All other patches for the same aircraft component must reside after the patch with the "last patch" toggle set (TNODS=5).

When saving a patch, LOFTSMAN automatically takes care of all CMARC input formatting. A patch, as formatted by LOFTSMAN, assumes additional patches will follow in the CMARC input file. Therefore, the last segment's TNODS variable is set TNODS=3. When the patch is the last patch in the input file, the TNODS variable must be manually set to TNODS=5. If CMARC hangs up while reading in geometry information, most likely TNODS=5 is missing on the last patch.

### ***a. Fuselage Model***

The fuselage is lofted as a B-type body. A B-type body is used when major portions of the fuselage have a circular or oval cross section. The input file is listed in Appendix B. Only the right side is meshed, with a symmetric left side created by toggling the IPATSYM variable to IPATSYM=1. LOFTSMAN assumes that B-type bodies converge to a specific point at the fore and aft ends. The flat aft fuselage face does not provide this single point. A slight modification was made to the aft face to allow automatic meshing as a B-type body. The center of the aft face is extended very slightly, approximately 1/8 inch, to provide a convergence point for the final rear triangular panels. This small deviation is assumed not affect the aerodynamic fidelity of the model for a potential flow solution.

The right side was originally meshed separately from the wing as a 20 x 20 panel patch. This created a low order fit when the wing patch was butted to the side of the fuselage, resulting in overlapping panels. A final mesh was created that flowed around the wing root and fuselage intersection for a high order fit. All the fuselage panels at the wing root join with the adjacent wing panels. This mesh requires that the fuselage be broken up into six separate panels per side. They are the nose patch, the forward transition patch, the top and bottom wing root patches, the aft transition patch and finally the rear fuselage patch. Some manual editing is required to straighten out panels on the upper fuselage patch. When the six patches are added together, the final configuration is modeled with a 44x15 panel patch.

### ***b. Main Wing Patch***

The NACA 2415 wing is created with four separate patches to allow the addition of a deflected aileron mesh. CMARC comes with a broad selection of "\*.SD" airfoil template files that are automatically loaded during installation. The "NACA2415.SD" file is used for this model. The 10x15 inboard wing patch runs from the wing root, past the flaps, to the start of the aileron. The 10x15 mid-wing patch covers the portion of the wing spanned by the aileron. The tapered outboard wing extension is made with a 6x15 patch. Finally, a 4x15 semi-circular wing tip patch is created using CMARC's built-in wing tip functionality. The wing is set to a 4.5° incidence in the LOFTSMAN input file. Alternatively, the patch could be created with no incidence and then the patch coordinate system could be rotated in the CMARC input file. Together, the three wing patches add to make a 30x15 panel wing model.

The ailerons are meshed at zero degree deflection and five degrees of right rolling moment deflection. For the no deflection case, a single right wing patch is meshed with CMARC's symmetric patch toggle (IPATSYM=1) creating the left patch. For deflected ailerons, separate patches are meshed for each wing. The right wing aileron deflection is five degrees trailing edge up (T.E.U.) and the left wing five degrees trailing edge down (T.E.D.).

### *c. Horizontal Stabilizer Patch*

The horizontal stabilizer and elevator patch is created with a single 10x16 mesh using the "NACA0006.SD" airfoil template. As stated earlier, the actual UAV horizontal stabilizer has flat upper and lower surfaces and a rounded leading edge. The NACA 0006 airfoil is substituted because it provides a close approximation to the leading edged radius and thickness ratio. No other special modifications are required. A tip patch is not added because some of the resulting panels would be too small. In particular, the triangular panels closing out the aft end of the tip are too small in proportion to the other panels, creating singularities due to machine resolution. Initially, an attempt was made to model horizontal and vertical stabilizer wing tips, but the model would not converge with them. Leaving off tip patches does not significantly influence results according to the CMARC User's Guide [Ref. 3].

The elevator spans the entire horizontal stabilizer. Two patches are meshed, one with zero deflection and the second with positive five degrees (+5° T.E.D.) of deflection. The deflected patch is used to obtain the elevator control power derivatives ( $C_{L\delta_e}$ ,  $C_{M\delta_e}$  and  $C_{D\delta_e}$ ).

### *d. Vertical Stabilizer Patch*

Two different versions of the vertical stabilizer are used for FROG modeling. An extended vertical stabilizer, which includes the "effective" area of the empennage tail boom, is used to measure the static sideslip and yaw rate damping derivatives. It is a 10x14 panel patch. The second patch models the actual area of the vertical stabilizer. It is a 10x12 patch and is meshed with a five-degree rudder deflection for measuring control power derivatives.

The vertical stabilizer and rudder patches are created with a single mesh using the "NACA0006.SD" airfoil template. As with the horizontal tail stabilizer, the NACA 0006 airfoil closely approximates the vertical surface leading edge radius and thickness ratio. The LOFTSMAN input file is different in that a vertical wing surface

requires a modification to the rib axis. The rib axis must be specified with an x-axis rotation of  $90^\circ$ , a y-axis rotation of  $0^\circ$  and an unspecified (999.0) z-axis rotation. No symmetry is selected for the vertical stabilizer because the patch is already symmetric about the  $y=0$  plane. As with the horizontal stabilizer, a tip patch is not added because some of the resulting panels would be too small.

The rudder spans the entire vertical stabilizer. Two patches are meshed, one with zero deflection and the second with positive five degrees ( $+5^\circ$  T.E.L.) of deflection. The deflected patch is used to obtain the elevator control power derivatives ( $C_{L\delta_e}$ ,  $C_{M\delta_e}$  and  $C_{D\delta_e}$ ).

#### *e. Tail Boom Patch*

The tail boom patch is created as a single  $12 \times 10$  mesh using a B-type body. Again, only the right side is meshed due to symmetry. The LOFTSMAN input file requires modifications at both ends in a similar fashion to the aft fuselage. A single point is added to allow convergence of the triangular panels at either end. With this point, the tail boom has the appearance of being tapered at both ends. The point is then manually edited out in the CMARC input file by replacing the "x" coordinate of the beginning and ending section panels with the correct value. In most cases, the tail boom is left out of solution to aid in convergence. This is due to the small overlapping panels at the fuselage tail boom junction. Being a slender, round tube directly in the fuselage slipstream, the tail boom is assumed to have a small influence on the stability derivatives.

#### *f. Engine Pod Patch*

The engine pod patch, or nacelle, is created as a single  $15 \times 10$  mesh using a B-type body. Only the right side is meshed due to symmetry. The prop spinner is an integral part of the patch. No attempt is made to model the prop, engine heads or exhaust system. As with the tail boom, in most cases the engine pod is left off the model used to establish stability derivatives.

#### *g. Engine Pylon Patch*

The engine pylon patch is modeled with a single  $15 \times 10$  mesh using an A-type body. A-type bodies are used to model surfaces similar to boat hulls with cornered surfaces or sharp chines. In addition, A-type bodies do not require the body to be completely enclosed. As a result, an A-body was selected to model just the sides of the pylon. Only the right side is meshed due to symmetry. A low order fit is achieved with

the adjacent fuselage and engine pod panels. This results in questionable pressure distributions. As a result, the pylon patch was turned off for most configurations. A future attempt could be made to create a high order fit between the other patches or to model the pylon as a flat surface. This will probably require manual editing of the intersecting patches. Even with a high order fit, a wake cannot be added to the trailing edge of the pylon. It would impact the vertical tail surface

#### **4. Common CMARC Input File Errors**

The patches created in LOFTSMAN are assembled into a single CMARC input file with any text editor. The default input file, which comes with CMARC, or any old input file may be modified. There are many errors that will cause CMARC to hang up without an error message. The two most common errors are forgetting to designate the last patch and incorrectly numbering the wake patches.

The last patch must be designated by including a TNODS=5 setting in the last section of the last patch. If it is not included, CMARC hangs up when reading in the geometry. In a similar manner, the last wake must be designated with a NODEW=5 setting. If the last wake is not designated, CMARC hangs up while reading in the wake information. Another common error involves incorrect wake to patch number association. Patch numbering changes whenever patches are disabled or reordered. The KWPACH field for each wake definition must be checked to make sure it reflects the current patch numbering.

#### **D. STATIC-PRESSURE SOURCE AND ALPHA VANE CORRECTIONS THROUGH OFF-BODY FLOW ANALYSIS**

CMARC is ideally suited for off-body flow analysis. Off-body streamlines may be placed through a point anywhere in the flow field. CMARC will then follow the streamline up and downstream the distance designated in the input file. This is particularly useful for flow visualization. In addition, CMARC calculates pressure coefficient and velocity at each point along the streamline. For this study, two streamlines are placed through the locations of the static-pressure source and alpha probe locations. Pressure coefficient is used to quantify static source position error and velocity is used to calculate alpha probe position error as a function of FROG UAV angle-of-attack. Both static pressure and AOA are digitized for down link to the ground station allowing the values to be easily corrected. Either a look-up table or curve fit correction can be applied subsequent to being passed to the flight control routines. This analysis

was previously published by the author in Ref. [1], but is included here to provide a single source of UAV modeling conducted to date.

### **1. Description of the FROG UAV Pitot-Static and AOA Systems**

The pitot-static system and angle-of-attack probe share a common flight test boom extending from the nose of the UAV. The boom contains both the total and static pressure ports. Figure 4.3 depicts the general dimensions of the flight test boom installation and the modeling coordinate system.

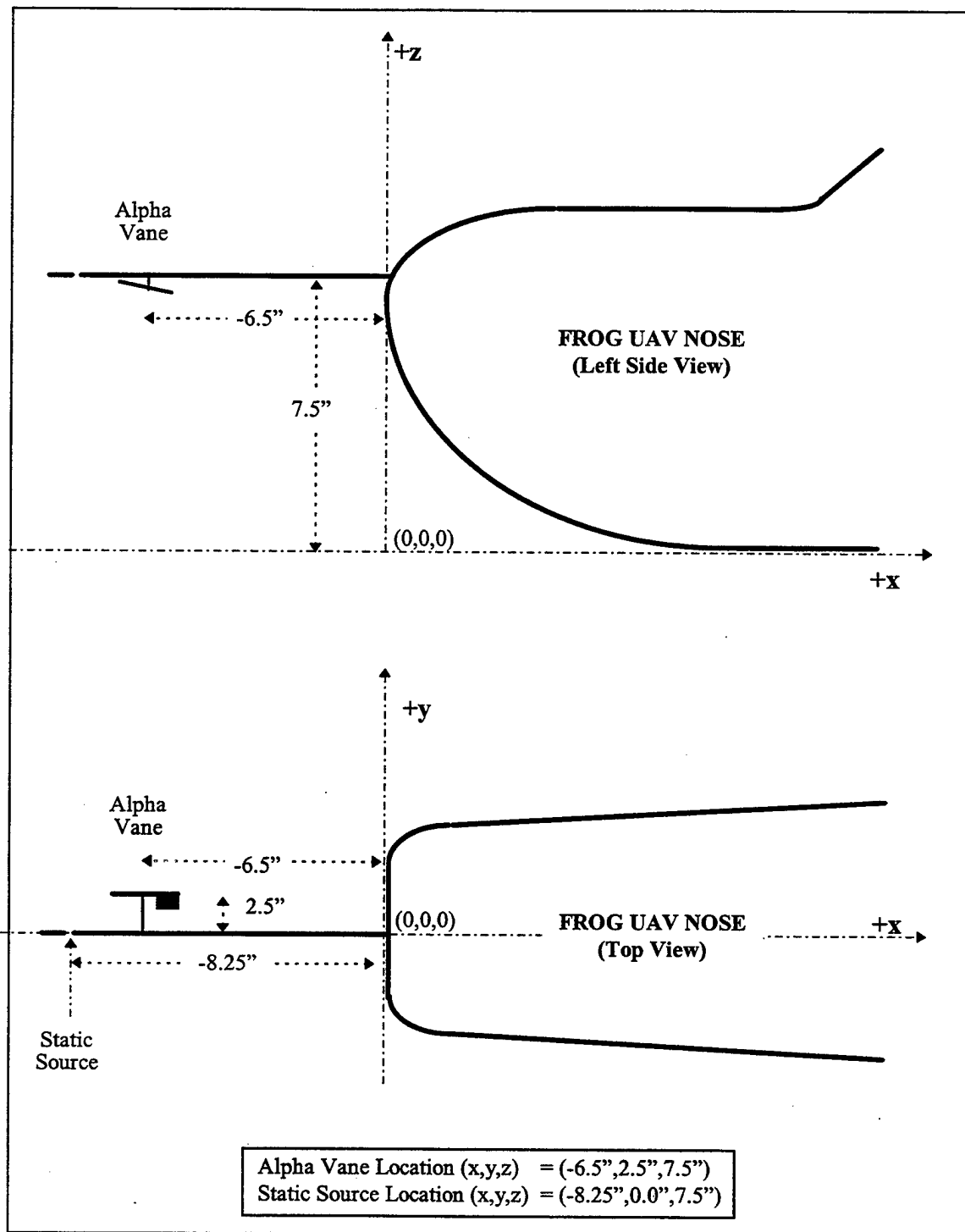
### **2. Modeling Off-Body Streamlines**

Streamlines are placed at the two locations indicated in Figure 4.3, which correspond to the static source and alpha probe locations. Two off body streamlines were activated in CMARC by setting NSTLIN=2 in the &SLIN1 line. Only a short distance of 2 inches is selected up and downstream in the SU and SD fields to reduce the size of the output file. Figure 4.4 is a POSTMARC rendering of the two off-body streamlines used for sensor corrections. With the model at  $\alpha_t=0^\circ$ , notice that the streamline is curving up at the angle-of-attack vane location 6.5 inches in front of the aircraft nose.

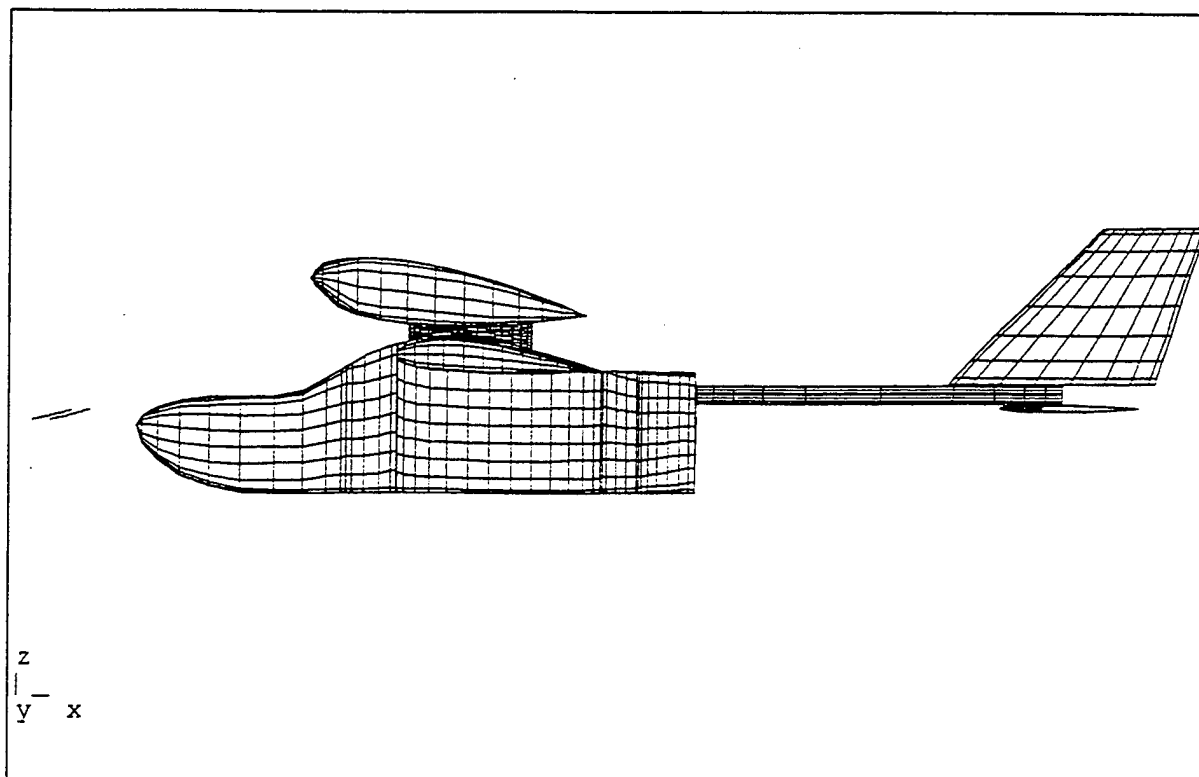
### **3. Analysis of Static Source Position Errors**

The position error pressure coefficient,  $\Delta C_{P_{pc}}$  or  $\Delta P_p/q_c$ , is a function of free stream Mach number and angle-of-attack provided that the static source is located outside of a thick boundary layer and sideslip is minimized [Ref. 11]. In the case of the FROG UAV with incompressible flow,  $\Delta P_p/q_c$  becomes a function of angle-of-attack only. Therefore, corrections can be simply defined as a function of measured angle-of-attack.

A DOS batch file was executed to step the CMARC model through angles-of-attack ranging from  $-8^\circ$  to  $20^\circ$ . The batch file incremented the angle-of-attack using CMARC's command line override feature. In addition, a new output file name was designated for each angle-of-attack. Position error pressure coefficient is then read from the off-body streamline listing of the output file at the location corresponding to the static source. Table 4.3 lists the values of  $\Delta P_p/q_c$  calculated from CMARC data. Figure 4.5 displays  $\Delta C_{P_{pc}}$  as a function of indicated angle-of-attack. The second order influence of angle-of-attack is clear with a second order curve fitting tightly through the data points. Of note, the error is relatively constant for a  $\pm 8^\circ$  band around trim angle-of-attack. For incompressible flow, position error pressure coefficient is independent of airspeed and altitude.



**Figure 4.3** Diagram of the FROG UAV Pitot-Static and AOA Systems.



**Figure 4.4 FROG Off-Body Streamline Visualization with POSTMARC ( $\alpha=10^\circ$ ).**

Position error pressure coefficient can be turned into position corrections for airspeed and altitude. The following relations were developed which assume small errors and incompressible flow:

$$\Delta V_{pc} = \frac{V_i \Delta C_p}{2} \quad \text{and} \quad \Delta V_{pc} = V_c - V_i \quad 4.1$$

$$\Delta H_{pc} = \frac{\Delta V_{pc} V_i}{\sigma_{std} g_0} \quad \text{and} \quad \Delta H_{pc} = H_c - H_i \quad 4.2$$

Where:

$\Delta H_{pc}$  is the altitude position correction.

$\Delta V_{pc}$  is the velocity position correction.

$\Delta C_p = \frac{\Delta P_p}{q_c}$  or position error pressure coefficient.

$\sigma_{std}$  is standard day density ratio.

$g_0$  is the gravitational constant.

Table 4.3 displays corrections calculated for both airspeed and altitude at the FROG UAV trim condition of 88 ft/s and 800 ft MSL. The corrections are added to the indicated value to obtain the corrected value. Figures 4.6 and 4.7 display the corrections as a function of indicated angle-of-attack. Again, a second order curve fits nicely through the data points. Equations 4.1 and 4.2 can be used to implement a correction algorithm based on airspeed and altitude.

#### 4. Analysis of Alpha Vane Position Error

Local flow field velocity is extracted from the off-body streamline listing to obtain local angle-of-attack. The alpha vane is assumed to capture the x-z component of the local velocity field and ignore cross flow in the y direction. Flow field velocity is turned into indicated angle-of-attack and angle-of-attack position correction with the following equations:

$$\alpha_i^\circ = \arctan\left(\frac{V_z}{V_x}\right) * \frac{180}{\pi} \text{ degrees} \quad 4.3$$

$$\Delta\alpha_{pc}^\circ = \alpha_t - \alpha_i \text{ degrees} \quad 4.4$$

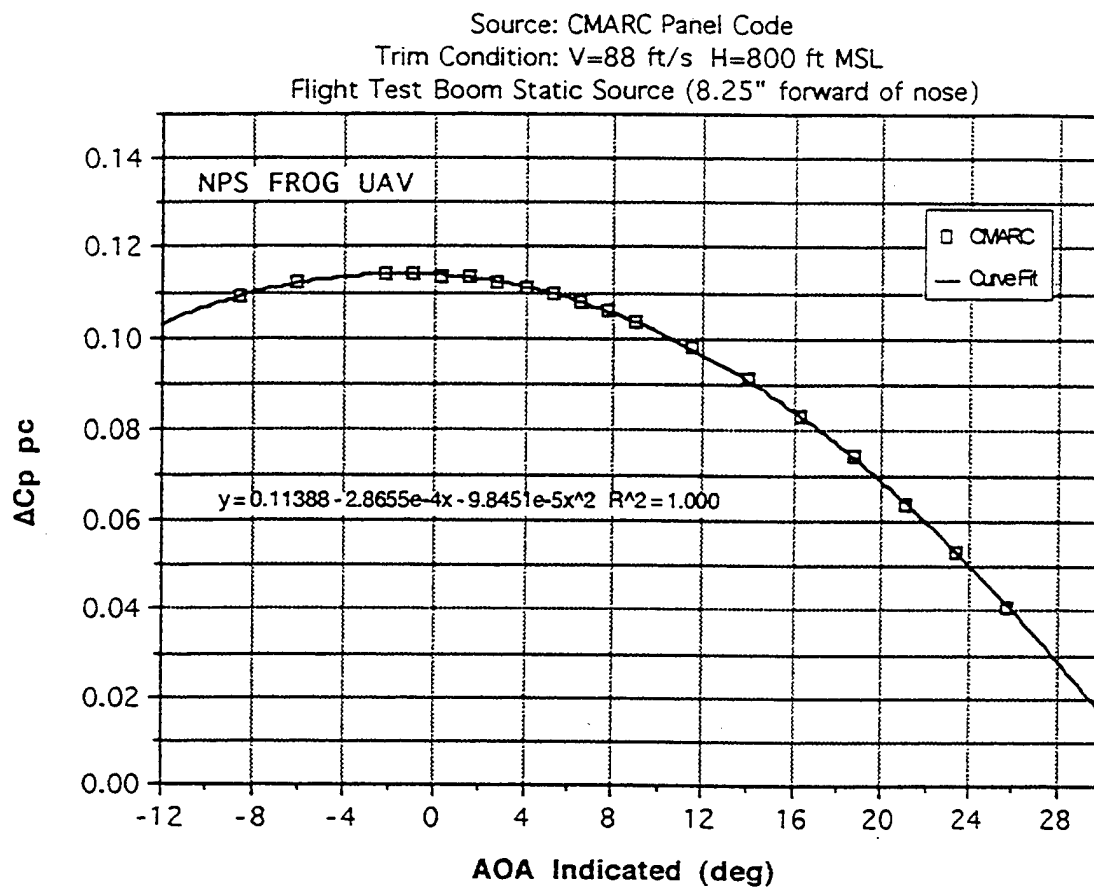
A DOS batch file is executed to step the CMARC model, with an off-body streamline located at the vane position, through angles-of-attack ranging from  $-8^\circ$  to  $20^\circ$ . Local velocity components are then read from the location corresponding to the alpha vane. Table 4.4 lists the values of  $\Delta\alpha_{pc}$  calculated from CMARC data. Figure 4.8 displays  $\Delta\alpha_{pc}$  as a function of indicated angle-of-attack. Linear and second order curve fit equations are also indicated on Figure 4.8. Angle-of-attack correction is fairly linear through the FROG operating envelope, with approximately  $-1.25$  degrees of position error at the FROG cruise trim condition. The corrections apply at all incompressible airspeeds and all altitudes.

#### 5. Summary of Off-Body Flow Field Analysis

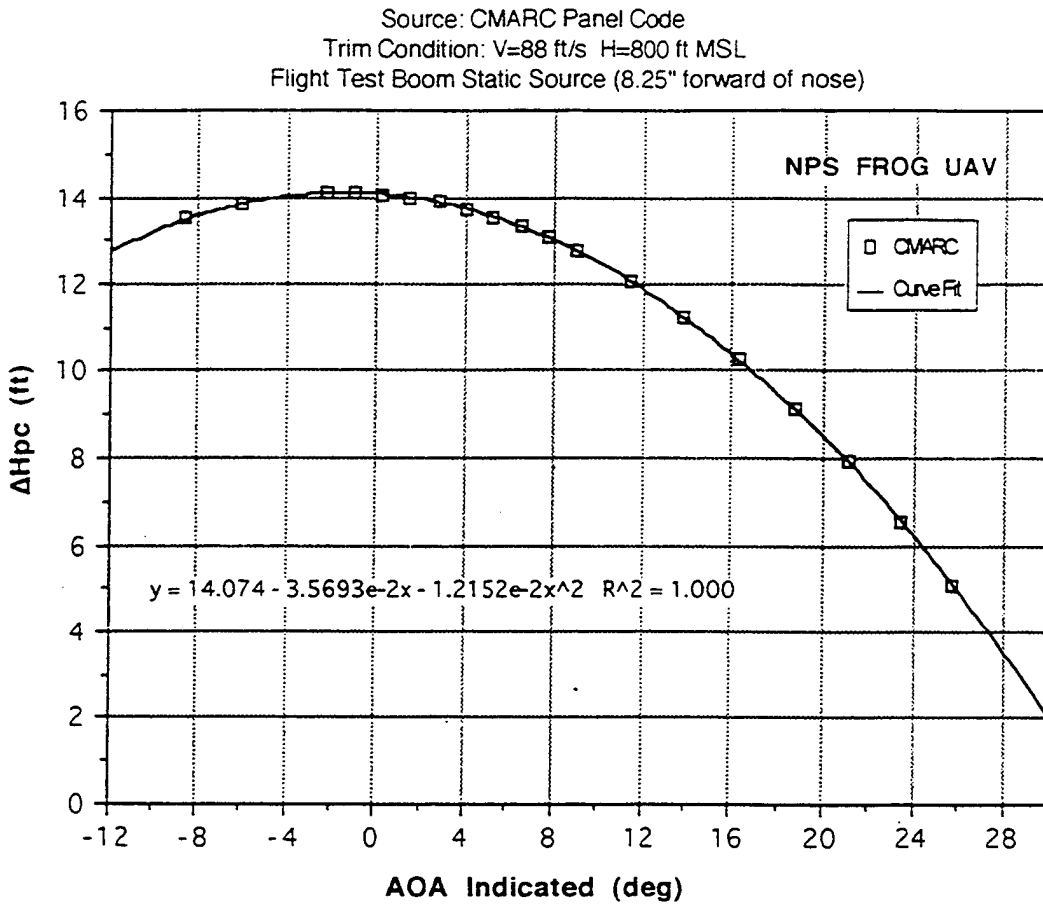
CMARC proved useful for both static-pressure source and alpha vane position corrections. Measured data may be corrected using look-up tables with the values in Table 4.3 and 4.4 or by using the curve fits in Figures 4.5 through 4.8. Flight testing is recommended for validation of sensor corrections obtained from this CMARC off-body flow field analysis.

<b>UAV AOA</b> $\alpha_T$ (deg)	$\Delta C_{p_{pc}}$ $\Delta P/q_c$	<b>V</b> Correction $\Delta V_{pc}=V_c-V_i$ (ft/s)	<b>H</b> Correction $\Delta H_{pc}=H_c-H_i$ (ft)
-8	0.1092	4.8	13.5
-6	0.1120	4.9	13.8
-3	0.1141	5.0	14.1
-2	0.1140	5.0	14.1
-1	0.1137	5.0	14.1
0	0.1132	5.0	14.0
1	0.1123	5.0	13.9
2	0.1111	4.9	13.7
3	0.1096	4.8	13.5
4	0.1078	4.8	13.3
5	0.1057	4.7	13.1
6	0.1034	4.6	12.8
8	0.0977	4.3	12.1
10	0.0909	4.0	11.2
12	0.0831	3.7	10.3
14	0.0741	3.3	9.2
16	0.0641	2.8	7.9
18	0.0530	2.3	6.6
20	0.0410	1.8	5.1

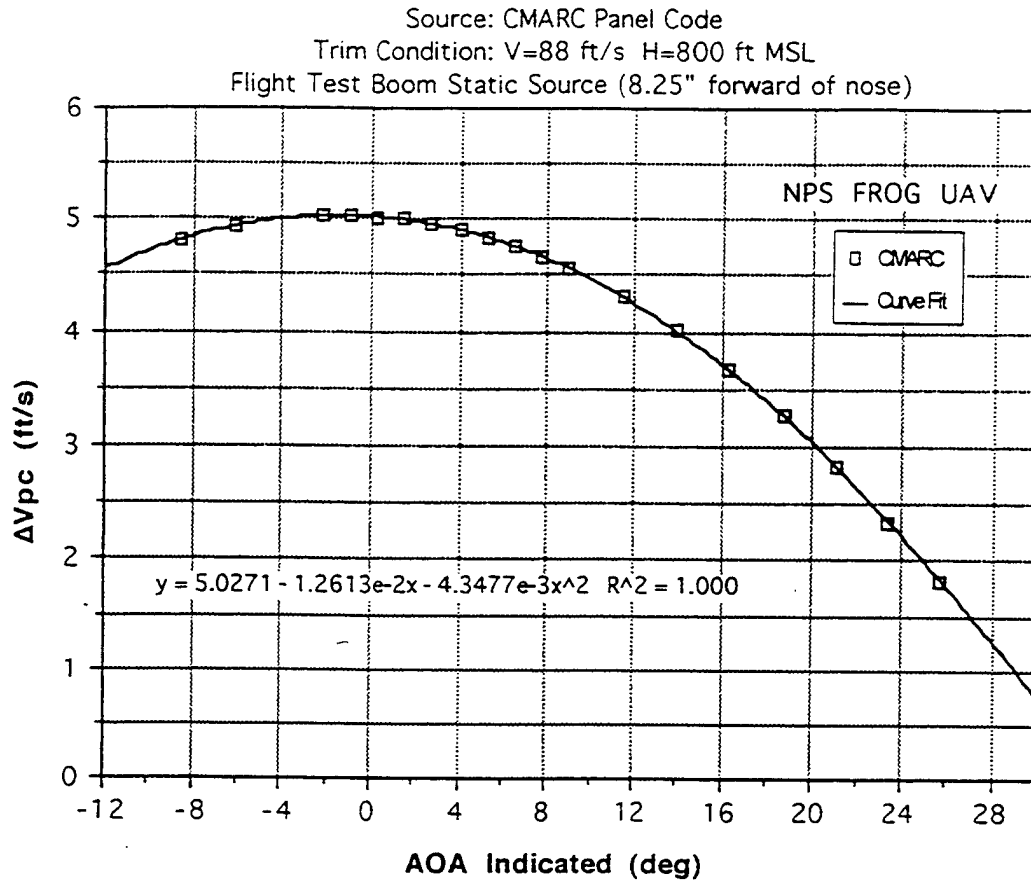
**Table 4.3      Position Error Corrections for the NPS FROG UAV at V=88 ft/s and H=800 ft MSL. Derived from CMARC Panel Code Off-Body Flow Field Analysis.**



**Figure 4.5** Position Error Pressure Coefficient,  $\Delta C_{p_{pc}}$ , for the NPS FROG UAV. Derived from CMARC Panel Code Off-Body Flow Field Analysis.



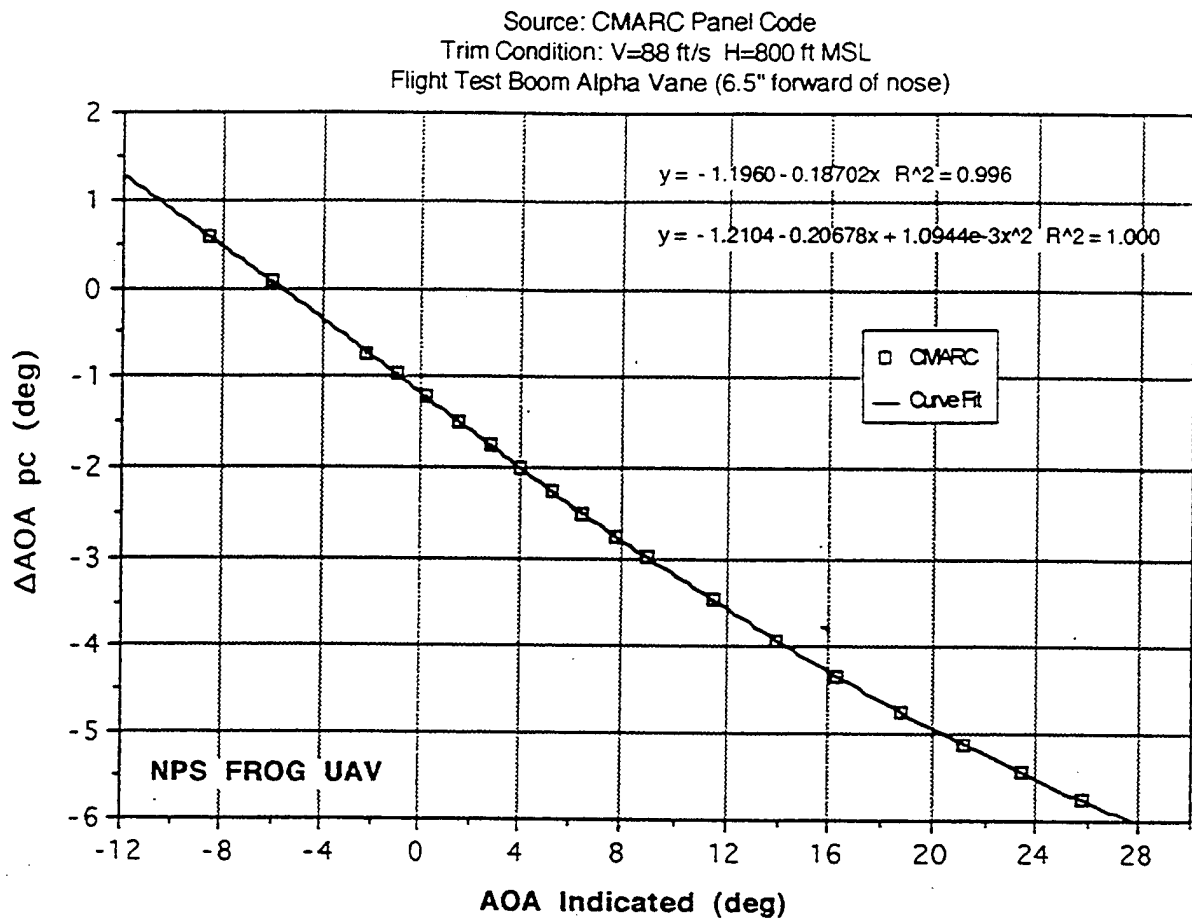
**Figure 4.6** Altitude Position Error,  $\Delta H_{pc}$ , for the NPS FROG UAV at V=88 ft/s and H=800 ft MSL. Derived from CMARC Panel Code Off-Body Flow Field Analysis.



**Figure 4.7** Airspeed Position Error,  $\Delta V_{pc}$ , for the NPS FROG UAV at V=88 ft/s and H=800 ft MSL. Derived from CMARC Panel Code Off-Body Flow Field Analysis.

UAV AOA $\alpha_T$ (deg)	Velocity at Alpha Vane			AOA Correction $\Delta\alpha = \alpha_T - \alpha_i$ (deg)	AOA Indicated $\alpha_i$ (deg)
	$V_x$ (ft/s)	$V_y$ (ft/s)	$V_z$ (ft/s)		
-8	80.92	1.66	-12.23	0.60	-8.60
-6	81.27	1.65	-8.65	0.08	-6.08
-3	81.60	1.64	-3.21	-0.75	-2.25
-2	81.67	1.63	-1.47	-0.97	-1.03
-1	81.71	1.63	0.28	-1.20	0.20
0	81.73	1.62	2.13	-1.49	1.49
1	81.73	1.61	3.93	-1.75	2.75
2	81.70	1.60	5.72	-2.00	4.00
3	81.66	1.59	7.51	-2.25	5.25
4	81.58	1.58	9.30	-2.50	6.50
5	81.48	1.57	11.08	-2.75	7.75
6	81.37	1.56	12.88	-2.99	8.99
8	81.07	1.53	16.43	-3.46	11.46
10	80.67	1.51	19.98	-3.91	13.91
12	80.17	1.48	23.50	-4.34	16.34
14	79.61	1.46	26.99	-4.73	18.73
16	78.93	1.43	30.47	-5.11	21.11
18	78.18	1.39	33.90	-5.44	23.44
20	77.34	1.36	37.31	-5.75	25.75

**Table 4.4     Angle-of Attack Vane Position Error Corrections for the NPS FROG UAV. Derived from CMARC Panel Code Off-Body Flow Field Analysis.**



**Figure 4.8** Angle-of-Attack Vane Position Error,  $\Delta\alpha_{pc}$ , for the NPS FROG UAV.  
 Derived from CMARC Panel Code Off-Body Flow Field Analysis.

## **E. DEVELOPMENT OF STABILITY DERIVATIVES**

In this section, CMARC is used to develop the longitudinal and lateral-directional stability derivatives for the FROG UAV. The development effort focuses on finding the static, rate-damping and control-power derivatives. The results obtained from CMARC are compared to data sets obtained from empirical estimation techniques and flight-test parameter estimation. In the next section, the stability derivatives are entered into a dynamic model to find modal frequency, damping and response to control deflections.

The potential flow analysis performed by CMARC does not provide accurate viscous drag values. Therefore, total drag is estimated from the flight-test power-off glide ratio and cruise thrust required. The User Guide developed in Appendix A describes in detail how to gather stability derivative data with CMARC. An abbreviated discussion is presented below.

CMARC contains built-in functionality to integrate forces and moments in all axes over the surface of a body. Force and moment coefficients are automatically nondimensionalized based on the mean aerodynamic chord, reference wing area, semi-span and center of gravity location in the CMARC BINP9 input line. Coefficients are presented in both wind and body axes. Of note, CMARC uses the semi-span to nondimensionalize rolling and yawing moment coefficients. Most texts on stability and control, including Roskam [Ref. 12] and Etkin [Ref. 13], nondimensionalize rolling and yawing moments by span. Rolling and yawing moments are nondimensionalized by span in this study. Table 4.5 summarizes the factors for normalizing moments and angular rates. All rolling and yawing moment coefficients presented in this study have been normalized with span by dividing the CMARC output by a factor of two. Table 4.5 also indicates the characteristic time,  $t^*$ , employed for angle rate data reduction.

In addition to differences in nondimensionalizing moments, CMARC uses the typical CFD axis system shown in Figure 4.9. For this study, all work is performed in the stability axis system. Figure 4.9 also illustrates the standard stability axes implemented in this study. The sign of CMARC roll and yaw moments need to be reversed. The direction for positive control deflections is also shown in Figure 4.9. All control surfaces are patched with positive deflections using the convention in Figure 4.9.

A potential flow solution will not produce satisfactory results for bodies with significant areas of flow separation. Therefore, CMARC models must be analyzed in the linear slope regions for valid results.

MOMENTS	NORMALIZING PARAMETER <sup>1</sup>	RATES	CHARACTERISTIC TIME
$L = C_l \bar{q} S b$	$b$	$\hat{p} = \frac{pb}{2u_o}$	$t^* = b/2u_o$
$M = C_m \bar{q} S \bar{c}$	$\bar{c}$	$\hat{r} = \frac{r\bar{c}}{2u_o}$	$t^* = \bar{c}/2u_o$
$N = C_n \bar{q} S b$	$b$	$\hat{r} = \frac{rb}{2u_o}$	$t^* = b/2u_o$

Note: 1) CMARC nondimensionalizes roll and yaw coefficients with  $b/2$ .

**Table 4.5 Nondimensionalized Moment and Rate Equations.**

For the static stability derivatives, the CMARC model is run at two different angles-of-attack and one sideslip angle with zero control surface deflections. The slopes of the force and moment coefficients are then taken to produce the  $C_{L\alpha}$  and  $C_{m\alpha}$  longitudinal derivatives and the  $C_{Y\beta}$ ,  $C_{l\beta}$  and  $C_{n\beta}$  lateral-directional derivatives.

For the control-power derivatives, the model is run at the trim condition with successive control deflections. The difference between the results with and without control surface deflections yield the  $C_{L\delta_e}$ ,  $C_{M\delta_e}$  and  $C_{D\delta_e}$  longitudinal and the  $C_{Y\delta_r}$ ,  $C_{l\delta_r}$ ,  $C_{n\delta_r}$ ,  $C_{l\delta_a}$  and  $C_{n\delta_a}$  lateral-directional control-power derivatives.

Development of the damping derivatives is not as straight forward. The static derivatives are obtained with motion disabled. For the longitudinal damping derivatives, the model is run with oscillating vertical plunging motion to obtain the  $C_L$  and  $C_M$   $\alpha$ -dot terms. The lift and pitching moment coefficients are broken into real (in phase with AOA) and imaginary (out of phase with AOA) components. The imaginary components are due to  $\alpha$ -dot effects. Next, the model is run with oscillating pitch motion to obtain the combined  $\alpha$ -dot and pitch rate terms. Subtracting the  $\alpha$ -dot influence obtained from the plunging motion isolates the pitch rate-damping term from the pitch motion.

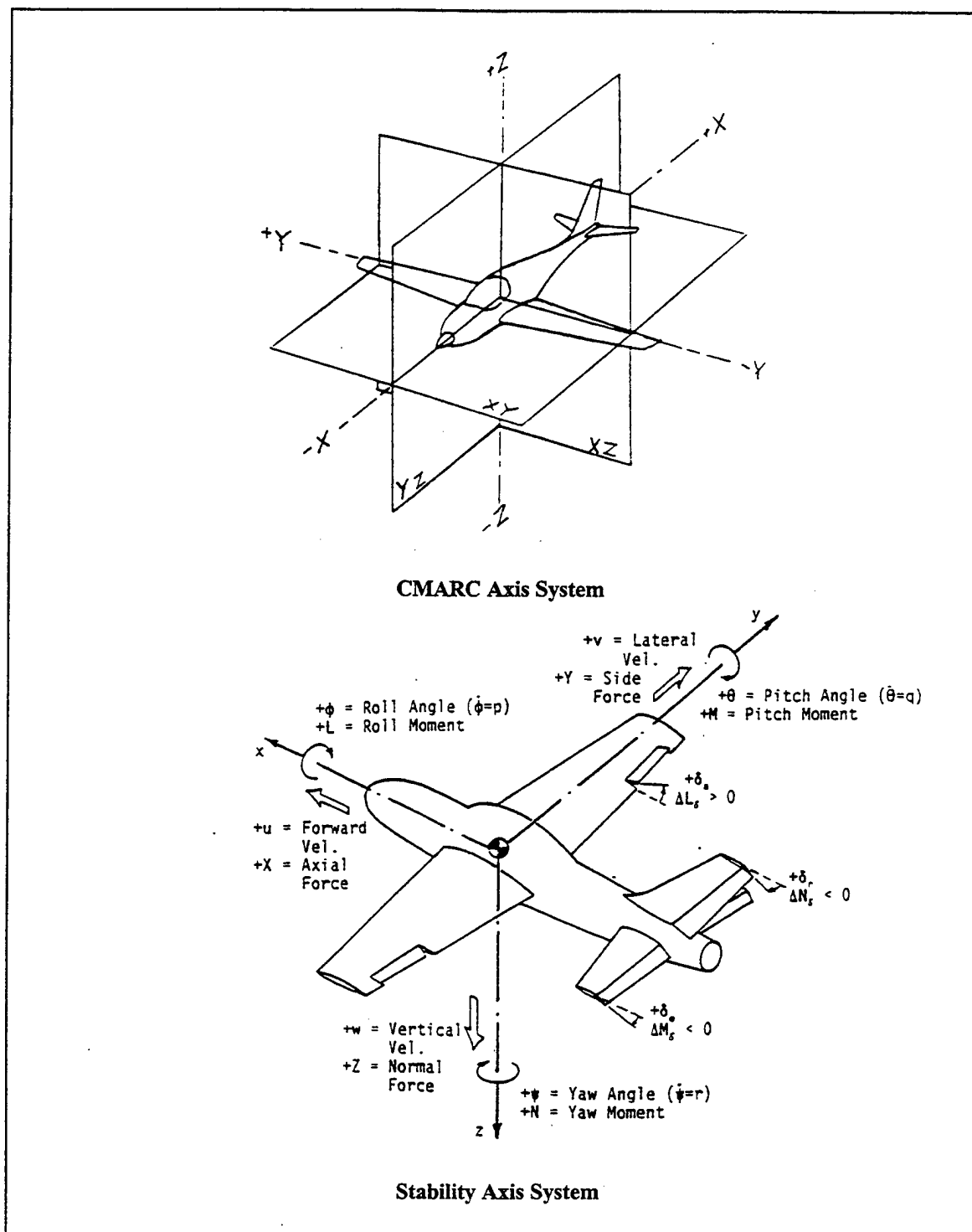


Figure 4.9 CMARC CFD Axis System Compared To Stability Axis System. From References [3] and [14] Respectively.

For the lateral-directional analysis, the  $\beta$ -dot terms are assumed to be small. This allows the model to be run with just oscillating roll and yaw motion. As with the longitudinal test case, the imaginary or out of phase component yields the combined  $\beta$ -dot and rate-damping data. With the  $\beta$ -dot terms assumed to be small, the oscillating motion yields the  $C_Y$ ,  $C_l$ , and  $C_n$  roll and yaw rate terms directly.

Throughout this chapter, stability derivatives obtained from CMARC are compared to three other data sets. The first comes from classical analysis through the methods presented by Roskam in References [12] and [15]. The second set comes from a classical aerodynamic model developed by Papageorgio [Ref. 2] and further refined through parameter estimation by Engdahl. The resulting parameter estimation model provides a good match to observed flight characteristics and is currently in use by the NPS Department for Aeronautical Engineering for closed-loop flight control development. The third set of data is for the Cessna 172 at the cruise flight condition. The data is only presented for an order of magnitude comparison.

## 1. Longitudinal Stability Derivatives

### a. *Static Longitudinal Stability Derivatives*

Three basic longitudinal stability derivatives can be measured with just two runs of the CMARC model. The model is first analyzed at an angle-of-attack corresponding to the estimated trim condition. In this case,  $\alpha_t=0^\circ$  is selected for the first run. A second CMARC run is conducted with angle-of-attack incremented by one or two degrees.  $C_L$  and  $C_m$  are then extracted manually from the data files. The slope of  $C_L$  and  $C_m$  versus angle-of-attack provide the  $C_{L\alpha}$  and  $C_{m\alpha}$  longitudinal derivatives. For this study, several angles-of-attack were analyzed to check consistency of the slope. In addition,  $\alpha_{trim}$  is calculated from the lift curve slope and trim lift coefficient. For the longitudinal analysis, only half the model is analyzed. The symmetric calculation mode is selected by setting both  $RSYM=0.0$  and  $IPATSYM=0$  in the CMARC input file. Equations 4.5 through 4.7 are used for these calculations:

$$C_{L\alpha} = \frac{(C_{L2} - C_{L1})}{(\alpha_2 - \alpha_1)} * \frac{180}{\pi} \text{ per radian} \quad 4.5$$

$$C_{m_\alpha} = \frac{(C_{m_2} - C_{m_1})}{(\alpha_2 - \alpha_1)} * \frac{180}{\pi} \text{ per radian} \quad 4.6$$

$$\alpha^\circ_{\text{trim}} = \alpha^\circ_1 + \frac{(C_{L_{\text{trim}}} - C_{L_1})}{C_{L_\alpha}} * \frac{180}{\pi} \text{ degrees} \quad 4.7$$

Two FROG UAV model configurations are analyzed in a build-up approach to check results against classical calculations and flight-test data. Figure 4.10 shows the CMARC models. First, just the wing and horizontal tail are considered. The patches for all other surfaces and wakes are turned off and the wing root is extended to centerline. Then, the blended wing/fuselage and horizontal tail are analyzed. Values of  $C_{L_\alpha}$  and  $C_{m_\alpha}$  for these two configurations are presented in Table 4.6.

Classical design calculations are also performed to estimate  $C_{m_\alpha}$  for comparison to CMARC results. Equation 4.8 is used for the calculation of  $C_{m_\alpha}$ :

$$C_{m_\alpha} = a_w \left[ (h - h_{ac}) - V_H \frac{a_t}{a_w} \left( 1 - \frac{d\varepsilon}{d\alpha} \right) \right] \quad 4.8$$

In classical design, the horizontal tail downwash derivative,  $d\varepsilon/d\alpha$ , is generally selected from empirical data. Using a taper ratio of  $TR=1:1$  and an aspect ratio of  $AR=6$ ,  $d\varepsilon/d\alpha=0.4$  is selected from empirical charts in Ref. [16] for the FROG UAV configuration. Also, calculations for  $d\varepsilon/d\alpha=0.25$  are included to illustrate pitching moment sensitivity to the downwash derivative. Table 4.6 lists  $C_{m_\alpha}$  for each configuration.

The final static longitudinal parameter required is total aircraft drag. Drag coefficient plays an important role in long-period aircraft dynamics. Unfortunately, potential flow panel codes such as CMARC do not provide accurate total drag estimates. They can provide good induced drag predictions. And, if equipped with a boundary layer code like that contained in CMARC, they can provide integrated skin friction results. However, a large total drag contribution in the form of pressure drag due to flow separation is not accounted for. Total drag estimates are made below using the two

simple techniques shown in Equations 4.9 to 4.12. The first method is based on flight-test glide ratio. The second is based on cruise power required and estimated prop efficiency. Note that the selected prop efficiency is relatively low due to the small propeller diameter, high RPM and pusher configuration. The two methods provide drag predictions within 10% of each other. The results are averaged to  $C_D=0.065$  and included in Table 4.6.

Method 1: Lift-to-Drag Ratio ( $L/D=7$  from flight-test)

$$\frac{L}{D} = 7 \Rightarrow D = \frac{L}{7} = \frac{W}{7} = \frac{67.7 \text{ lbs}}{7} = 9.67 \text{ lbs} \quad 4.9$$

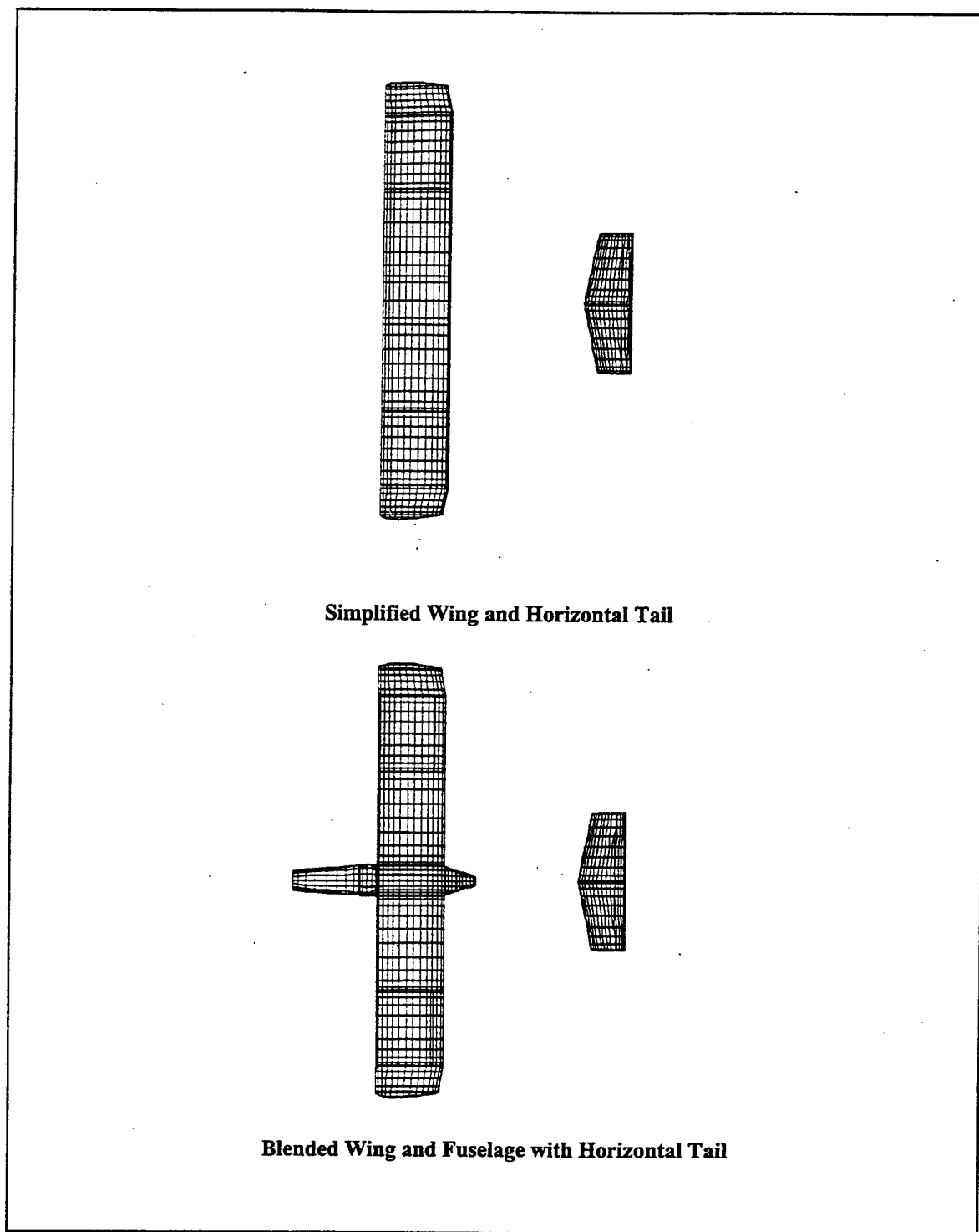
$$C_D = \frac{D}{qS} = \frac{9.67 \text{ lbs}}{0.5 * 0.002327 \text{ lb} \cdot \text{s}^2 / \text{ft}^4 * 88^2 \text{ ft}^2 / \text{s}^2 * 17.57 \text{ ft}^2} = 0.0611 \quad 4.10$$

Method 2: Cruise Power Setting ( $HP=5$ ,  $\eta_p=0.35$ )

$$C_D = \frac{D}{qS} = \frac{T_R}{qS} = \frac{HP_R * 550 \text{ ft} \cdot \text{lbs} / \text{s} / HP * \eta_p / V}{qS} \quad 4.11$$

$$C_D = \frac{5 \text{ HP} * 550 \text{ ft} \cdot \text{lbs} / \text{s} / \text{HP} * 0.35 / 88 \text{ ft} / \text{s}}{0.5 * 0.002327 \text{ lb} \cdot \text{s}^2 / \text{ft}^4 * 88^2 \text{ ft}^2 / \text{s}^2 * 17.57 \text{ ft}^2} = 0.069 \quad 4.12$$

Average:  $C_{D_{ave}} = (0.0611 + 0.069) / 2 = 0.065$



**Figure 4.10 CMARC Models of the FROG UAV for the Determination of Static Longitudinal Stability Derivatives.**

Flight-test data for the short-period and phugoid modes were used for longitudinal parameter estimation. Values for  $C_{L\alpha}$  and  $C_{m\alpha}$  based on preliminary parameter estimation work by Engdahl are presented in Table 4.6.

METHOD	CONFIGURATION <sup>1</sup>	STATIC LONGITUDINAL PARAMETERS				
		$\alpha_{trim}^2$ (deg)	$C_{L\alpha}$ (per rad)	$C_{m\alpha}$ (per rad)	$C_D$	$C_{D\alpha}$ (per rad)
CMARC Panel Code	Wing/Horiz Tail	-0.87	4.86	-0.835	n/a	n/a
	Wing/Fuselage/Horiz Tail	-0.01	4.85	-0.413	n/a	0.266
Classical Design <sup>3</sup>	Wing/Horiz Tail - $\delta\varepsilon/\delta\alpha=0.25$	-0.81	4.85	-1.00	n/a	n/a
	Wing/Horiz Tail - $\delta\varepsilon/\delta\alpha=0.40$	-0.82	4.82	-0.70	n/a	0.253
Parameter Estimation <sup>4</sup>	Flying Aircraft	n/a	4.09	-0.42	0.0655	n/a
	C-172 <sup>6</sup>	n/a	0.31	-0.89	0.31	0.13

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6"$  from bottom of fuselage.

2) Zero lift wing incidence is  $+6.5^\circ$  from the longitudinal reference line.

3) Classical design after Ref. [12].

4) Parameter estimation from NPS flight test data by Engdahl.

5) Average drag obtained from L/D and cruise power analysis from flight test data.

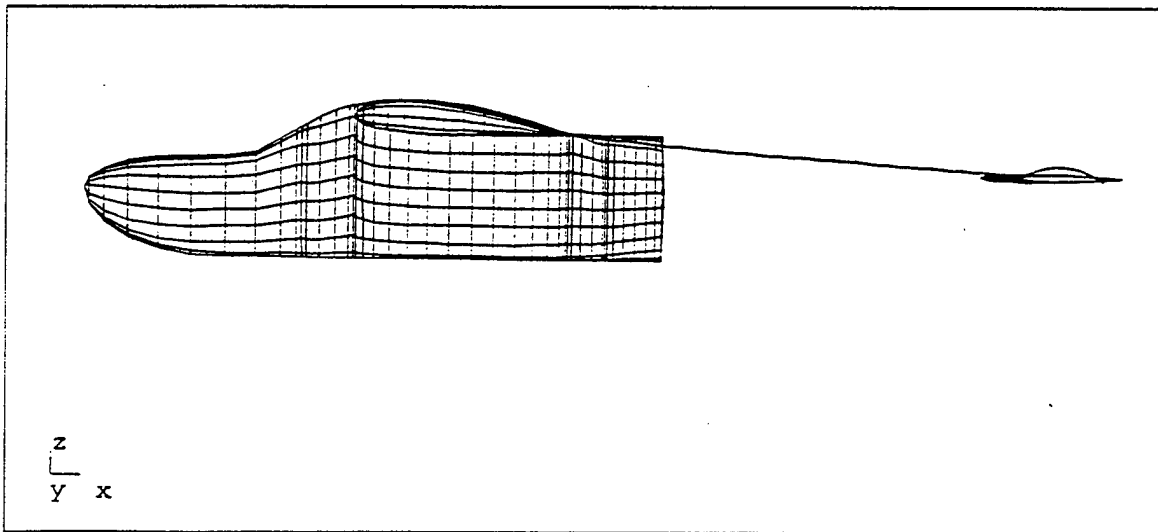
6) C-172 data from Ref. [12].

**Table 4.6 Comparison of FROG UAV Static Longitudinal Stability Derivatives.**

Good correlation of lift curve slope ( $C_{L\alpha}$ ) to classical design is demonstrated by the two CMARC configurations in Table 4.6. Both techniques over estimated  $C_{L\alpha}$  compared to flight-test data. Neither the classical design technique nor the CMARC model accounts for control surface leakage or separation effects. Modeling actual flight control gap geometry may provide a closer match to experimental data.

Excellent correlation is achieved for  $C_{m\alpha}$  between the blended wing/fuselage CMARC model and flight-test results. The low value of  $C_{m\alpha}$  implies that  $d\varepsilon/d\alpha$  is greater than the 0.4 value selected from empirical charts in Reference [16]. The simplified wing/tail model resulted in a  $C_{m\alpha}$  that closely matches classical design predictions with  $d\varepsilon/d\alpha=0.35$ . Clearly, CMARC modeling provides the value-added capability to capture fuselage influences that are missed with classical design methods.

An investigation was performed to see if improved wake definition could better capture the  $d\varepsilon/d\alpha$  downwash derivative. Initially a flexible wake was selected. However, at the cruise angle-of-attack, the flexible wake impacted the horizontal tail causing inaccurate results. A further investigation was made into a streamline based wake definition. A study by Walden et al. [Ref. 17] studied wake turbulence by modeling an aircraft flying in trail of a wake-generating wing. A horizontal tail trailing the main wing is a similar configuration. The study found that a streamline-based wake is the best method for modeling downwash effects. In the study, the model was initially run with a rigid-wake. A streamline was also defined downstream of the main wing trailing edge. After analyzing the first results, the wake was then predefined to follow the streamline. The result was a first iteration on modeling a flexible wake with a predefined rigid-wake. This technique was tried during the course of FROG UAV modeling. However, FROG geometry proved unsuited to this technique. The streamline trailing the wing ended up impacting the horizontal tail. This indicated that a predefined wake would also impact the horizontal tail, resulting in inaccurate result. Figure 4.11 shows the streamline impacting the horizontal tail at cruise angle-of-attack with rigid-wakes selected. With the already close correlation of the rigid-wake results to flight-test data, further efforts to investigate  $C_{m\alpha}$  were abandoned.

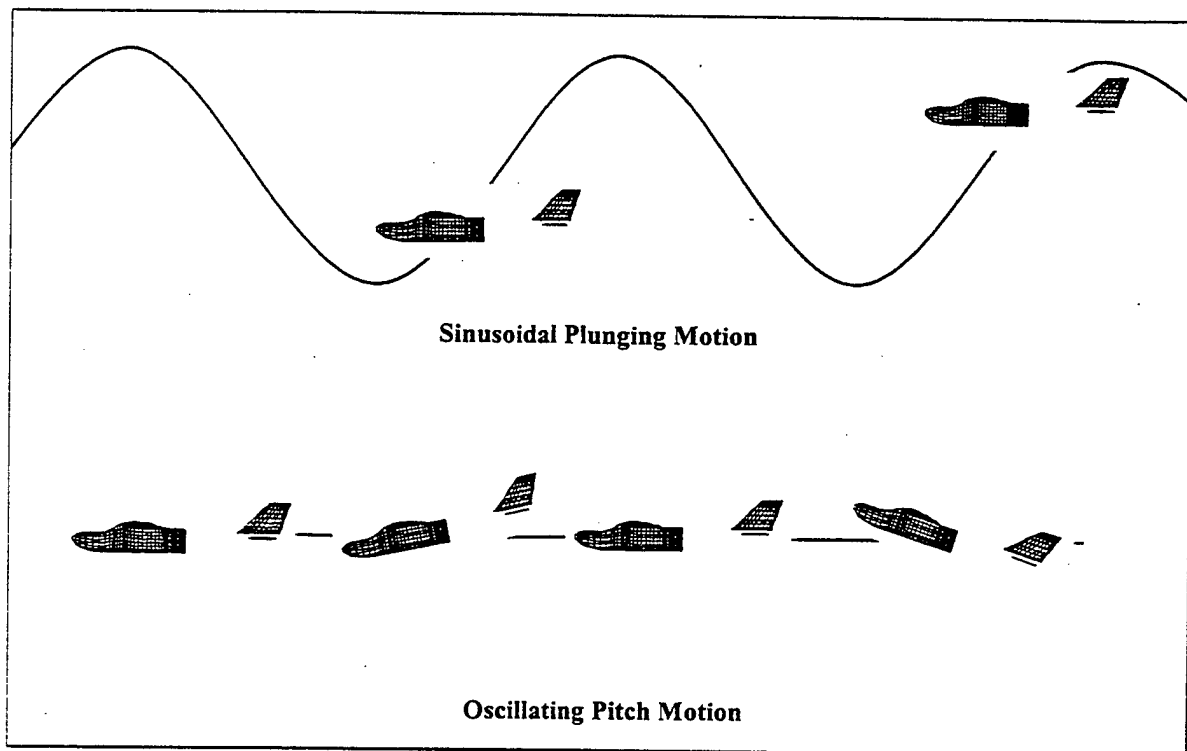


**Figure 4.11 Rigid-Wake Streamline for Investigation of Streamline Based Wake Definition.**

In summary, for the static longitudinal stability derivatives, CMARC produced accurate values for  $C_{m\alpha}$  and a slightly high value of  $C_{L\alpha}$ . Drag coefficient is obtained by averaging the values from the lift-to-drag ratio and cruise thrust required techniques.

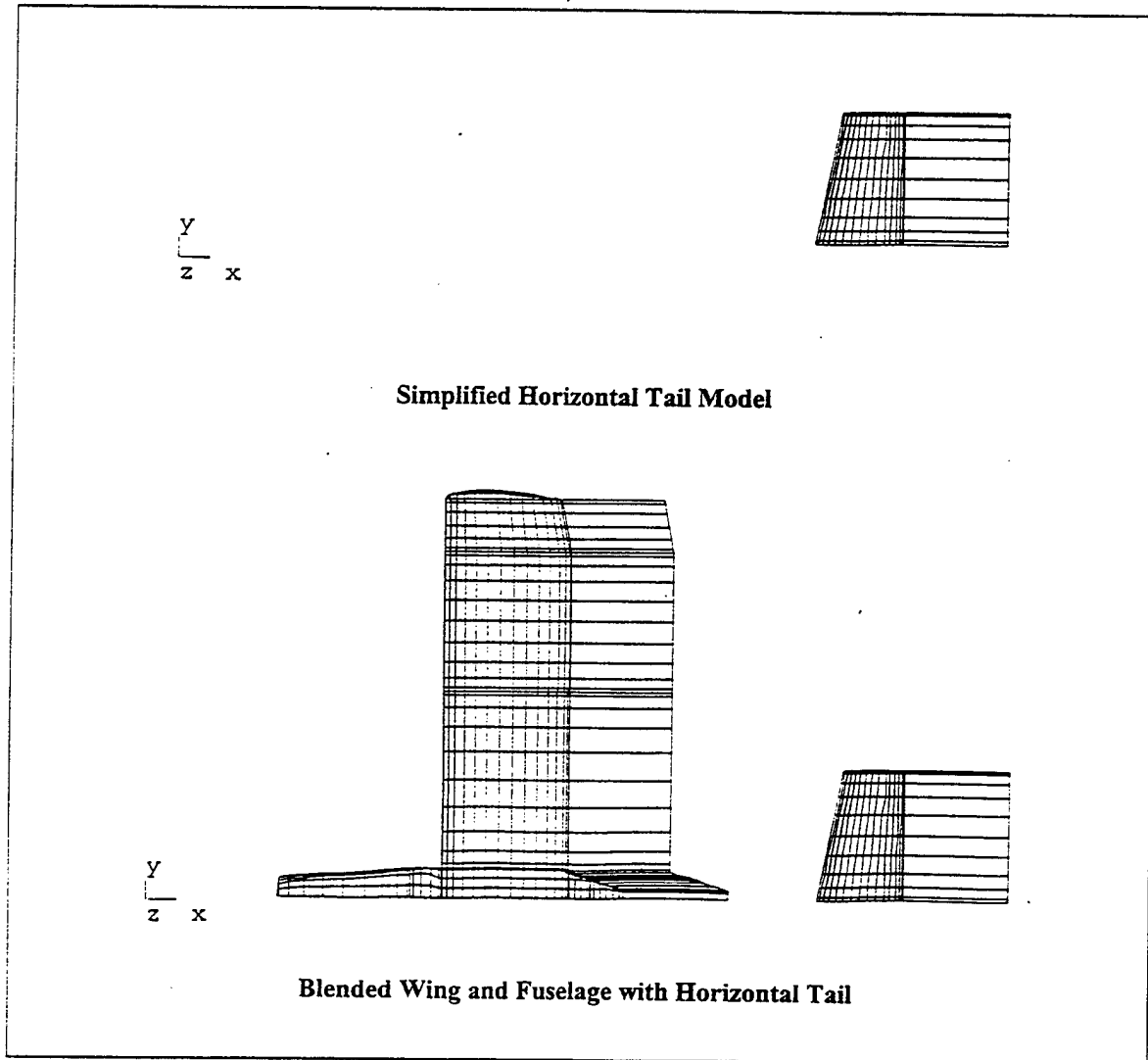
**b. Longitudinal Damping Stability Derivatives**

The two aircraft motions illustrated in Figure 4.12 are used to develop the longitudinal rate-damping derivatives. A sinusoidal vertical plunging motion isolates the  $\alpha$ -dot effects. Oscillatory motion is controlled with the CMARC BINP8A input file line. The oscillating pitch angle captures both the  $\alpha$ -dot and pitch rate-damping terms. It is controlled with the CMARC BINP8B input file line. The  $\alpha$ -dot influence developed from the plunging motion is subtracted from the pitching motion to isolate the pitch rate effect. All motion is conducted at a frequency of  $2\pi$  rad/s, which equates to a reduced frequency of  $k=0.0595$  for this configuration and trim airspeed.



**Figure 4.12 Aircraft Motion for the Determination of  $\alpha$ -dot and Pitch Rate Damping.**

The two models shown in Figure 4.13 are used for the rate-damping investigation. The complete wing/fuselage horizontal tail model is used for both the  $\alpha$ -dot and pitch rate-damping terms, while the simplified horizontal tail only model is used to obtain a first approximation of pitch rate-damping. The User Guide in Appendix A provides a more detailed description of the techniques used to gather the dynamic longitudinal stability derivatives.



**Figure 4.13 CMARC Models of the FROG UAV for the Determination of Longitudinal Rate-Damping.**

Traditional design calculations, from Roskam [Ref. 12], are used for comparison to CMARC and flight-test results:

$$C_{L_{\dot{\alpha}}} = 2 * C_{L_{\alpha_H}} * \eta_H * V_H * \frac{\partial \varepsilon}{\partial \alpha} \quad 4.13$$

$$C_{M_{\dot{\alpha}}} = -2 * C_{L_{\alpha_H}} * \eta_H * V_H * \frac{l_t}{\bar{c}} * \frac{\partial \varepsilon}{\partial \alpha} \quad 4.14$$

$$C_{L_q} = 2 * C_{L_{\alpha_H}} * \eta_H * V_H \quad 4.15$$

$$C_{M_q} = -2 * C_{L_{\alpha_H}} * \eta_H * V_H * \frac{l_t}{\bar{c}} \quad 4.16$$

where the dynamic pressure ratio at the tail is taken as  $\eta_H=1.0$

The dynamic longitudinal stability derivatives are presented in Table 4.7. CMARC-obtained values are compared to classical design values and C-172 stability derivatives. Flight-test data is unavailable for the damping derivatives. The aerodynamic model currently in use by the FROG research team implements longitudinal damping coefficients obtained from classical design techniques. The  $C_{L_{\dot{\alpha}}}$  and  $C_{m_{\dot{\alpha}}}$  obtained from CMARC for the complete model provided a good match to the classical design data. However, both  $C_{L_{\dot{\alpha}}}$  and  $C_{m_{\dot{\alpha}}}$  are over estimated by approximately 50% as compared to classical design values. One possible explanation for the additional damping from CMARC is that the classical approximation only estimates the horizontal tail influence on damping. CMARC also measures wing and fuselage damping influence. The horizontal tail by itself produces values close to the classical calculations. This supports the assertion that CMARC also captures the wing and fuselage influence for the whole model.

METHOD	CONFIGURATION <sup>1</sup>	DYNAMIC LONGITUDINAL PARAMETERS			
		$C_{L\dot{\alpha}}$ (deg)	$C_{Lq}$ (per rad)	$C_{m\dot{\alpha}}$ (per rad)	$C_{mq}$ (per rad)
Panel Code	Blended Wing-Fuselage/Horiz Tail	1.42	6.82	-6.24	-11.78
	Horizontal Tail only	n/a	4.37	n/a	-11.94
Classical <sup>2</sup>	Wing / Horizontal Tail	1.56	3.89	-4.14	-11.39
Par. Est <sup>3</sup>	Flying Aircraft	n/a	n/a	n/a	n/a
	C-172 <sup>4</sup>	1.7	3.9	-5.2	-12.4

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6"$  from bottom of fuselage.

2) Classical design after Ref. [12].

3) Parameter estimation from flight test data by Engdahl.

4) C-172 data from Ref. [12].

**Table 4.7 Comparison of FROG UAV Dynamic Longitudinal Stability Derivatives.**

*c. Longitudinal Control-Power Derivatives*

The elevator control-power derivatives are obtained by substituting a 0° deflection horizontal-tail patch for one with +5° trailing edge down deflection. Only one run is required. The difference between the trim condition and the deflected value is divided by the elevator deflection as shown below:

$$C_{L\delta e} = \frac{(C_{L\delta e_2} - C_{L\delta e_1})}{\delta e_2 - \delta e_1} * 57.3 \text{ per rad} \quad 4.17$$

$$C_{D\delta e} = \frac{(C_{D\delta e_2} - C_{D\delta e_1})}{\delta e_2 - \delta e_1} * 57.3 \text{ per rad} \quad 4.18$$

$$C_{m\delta e} = \frac{(C_{m\delta e_2} - C_{m\delta e_1})}{\delta e_2 - \delta e_1} * 57.3 \text{ per rad} \quad 4.19$$

Elevator control-power derivatives are presented in Table 4.8. A classical design estimate of elevator control-power is also shown for comparison. The following relationships from Roskam [Ref. 15] are used for estimating elevator control-power:

$$C_{L_{\delta e}} = C_{L_{\delta F}} * \frac{S_H}{S} \quad 4.20$$

$$C_{m_{\delta e}} = -C_{L_{\delta e}} * \frac{l_H}{c} \text{ or } C_{m_{\delta e}} = -C_{L_{\delta F}} * V_H \quad 4.21$$

where  $C_{L_{\delta F}}$  is the variation of lift coefficient with elevator deflection found from charts in Roskam [Ref. 15].

In general, the elevator control-power derivatives obtained with CMARC correlate well with classical design techniques. For both  $C_{L_{\delta e}}$  and  $C_{m_{\delta e}}$ , CMARC derived elevator power is approximately 15 percent higher than obtained from classical calculations. However, CMARC significantly under-estimates elevator control-power compared to the parameter estimation model. The most likely explanation for this phenomenon is that the CMARC solution does not model the effects of prop wash. The higher dynamic pressure over the horizontal stabilizer from prop wash increases elevator effectiveness. The parameter estimation model captures this phenomenon. This same trend can be seen in the modeling of rudder control-power. An attempt could be made to model the prop disk effects using CMARC's normal panel velocity definition capability.

METHOD	CONFIGURATION <sup>1</sup>	ELEVATOR CONTROL POWER		
		$C_{L_{\delta e}}$ (per rad)	$C_{D_{\delta e}}$ (per rad)	$C_{m_{\delta e}}$ (per rad)
Panel Code	Blended Wing-Fuselage/Horiz Tail	0.438	0.01	-1.199
Classical <sup>2</sup>	Wing / Horizontal Tail	0.39	n/a	-1.04
Par. Est <sup>3</sup>	Flying Aircraft	1.13	n/a	-1.62
	C-172 <sup>4</sup>	0.43	0.06	-1.28

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6"$  from bottom of fuselage.

2) Classical design after Ref. [12].

3) Parameter estimation from NPS flight test data by Engdahl.

4) C-172 data from Ref. [12].

**Table 4.8 Comparison of FROG UAV Elevator Control-Power Derivatives.**

## 2. Lateral Directional Stability Derivatives

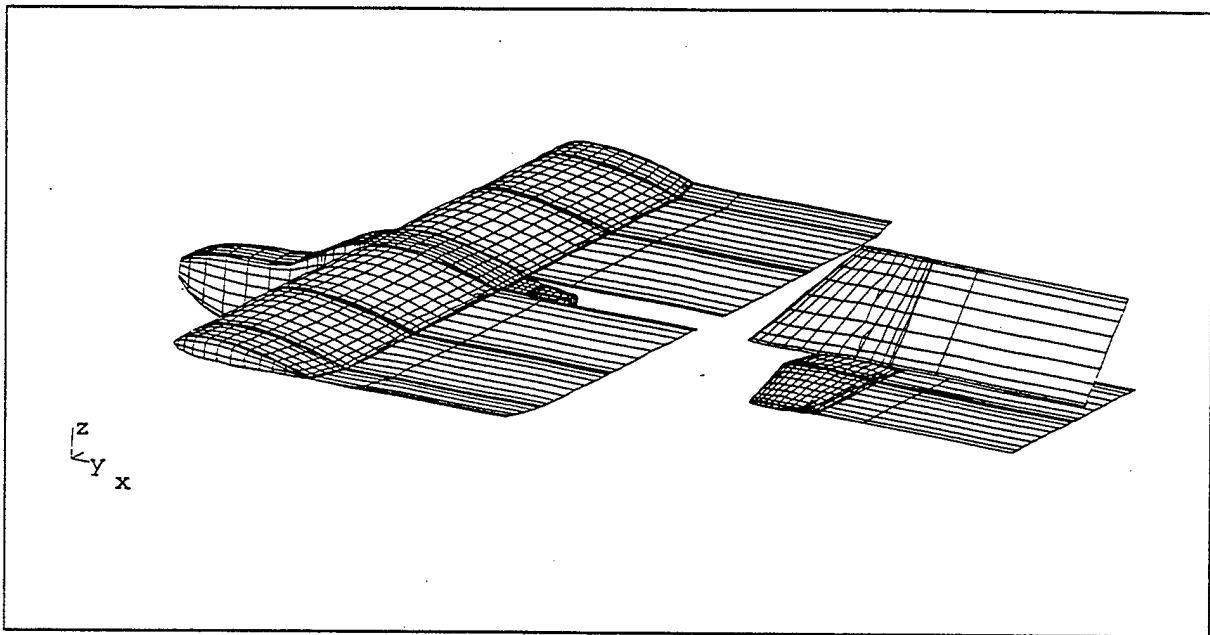
### *a. Static Lateral-Directional Stability Derivatives*

Development of the static lateral-directional stability derivatives is not as straightforward. Both sides of the airframe must be modeled by setting both  $RSYM=1.0$  and  $IPATSYM=1$ . This creates symmetric patches around the  $y=0$  plane allowing CMARC to perform asymmetric calculations around the entire body and significantly increases processing times.

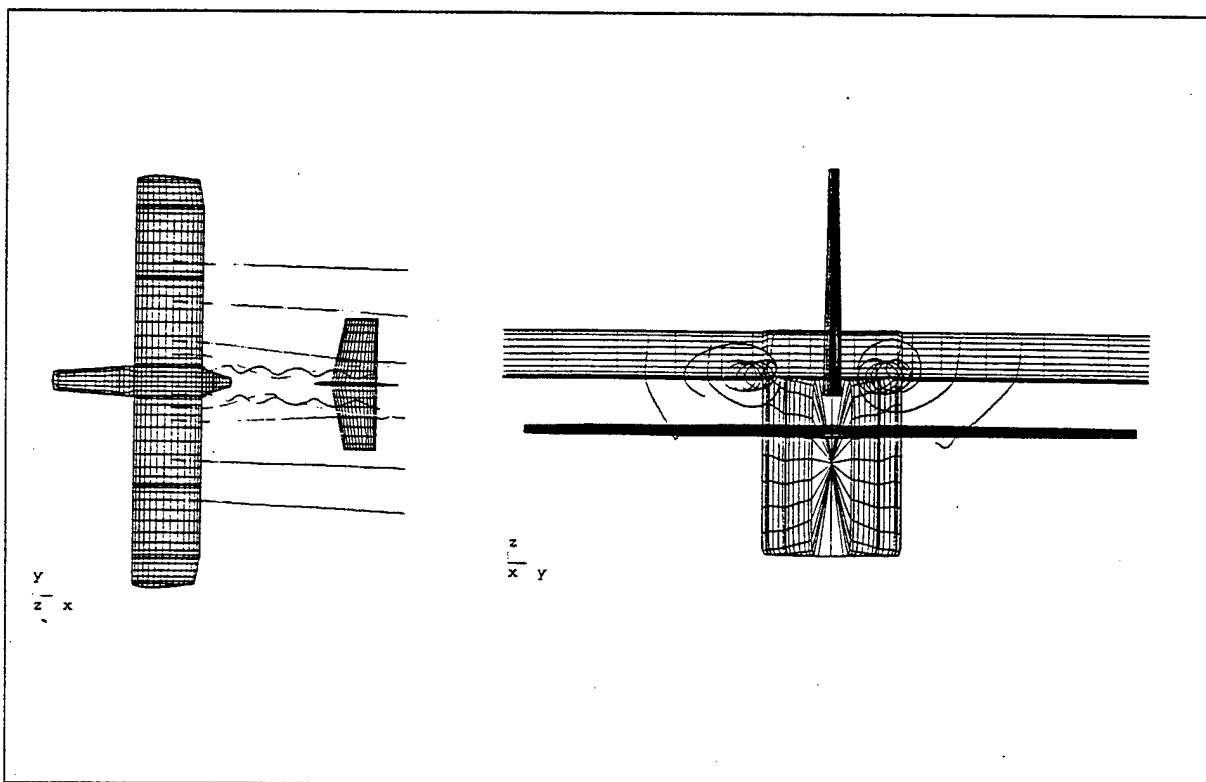
Initially, a lateral-directional solution was attempted with a complete airframe model. The longitudinal model was modified by adding the vertical stabilizer. This required what was perceived to be a minor wake modification. Figure 4.14 illustrates the configuration. The wing wake was terminated at the wing root to prevent interference with the vertical stabilizer. This left a wake gap for the vertical stabilizer. The engine nacelle and pylon patches were turned off because the wakes would also impact the vertical stabilizer. This configuration met with mixed success. The values of both  $C_{yb}$  and  $C_{nb}$  were opposite the expected directions. Under closer inspection, it was determined that the false vortex shed from the wing root caused a destabilizing influence on the vertical stabilizer. Figure 4.15 illustrates the vortex using CMARC's built in off-body streamline capability.

In order to obtain satisfactory results, the model is broken up into two separate groups. The aircraft is modeled with the blended wing and fuselage as one group and the horizontal and vertical stabilizers as another group. Separate solutions are obtained for each group and summed through superposition to obtain the whole aircraft solution. The two separate models are shown in Figure 4.16. This method should be used as a last resort. A complete solution should be used if the airframe geometry allows adequate wake separation from the vertical stabilizer. A complete solution would capture fuselage, wing and vertical stabilizer interactions.

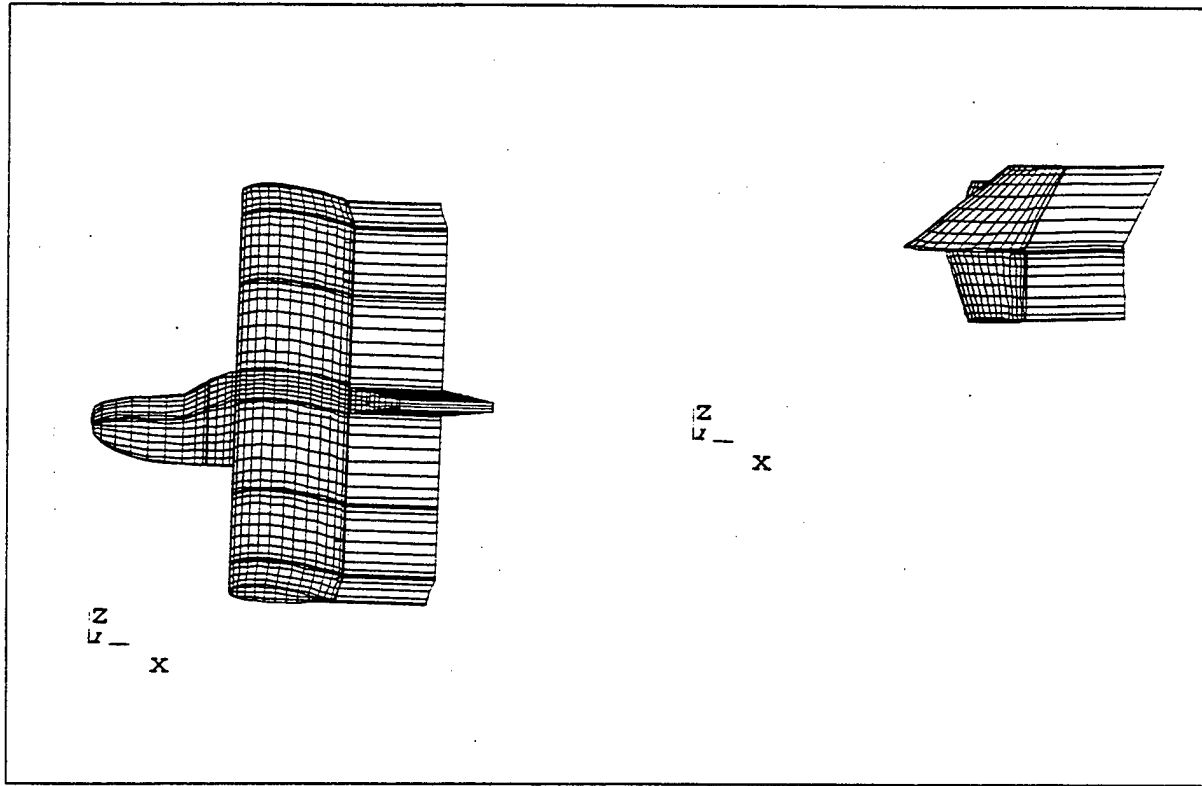
Once the model is defined, it is checked for lateral-directional balance at zero sideslip angle (yaw angle= $0^\circ$ ). The side force, rolling and yawing coefficients should be zero when a trial run is performed at zero sideslip. If lateral-directional forces or moments are present, the model and wake geometry should be checked for symmetry.



**Figure 4.14 Unsuccessful Lateral-Directional Model of the FROG UAV. False Wing Root Vortex Caused Destabilizing Influence on the Vertical Stabilizer.**



**Figure 4.15 Destabilizing Wing Root Vortex Visualized with Off-body Streamlines.**



**Figure 4.16 Final Simplified Lateral-Directional Models of the FROG UAV. Separate Solutions are Summed to Obtain Complete Airframe Solution.**

Next, a single CMARC run is performed with  $\alpha = \alpha_{\text{trim}}$  and with two degrees of yaw angle. The results from both models are summed. The lateral-directional derivatives,  $C_{Y\beta}$ ,  $C_{l\beta}$  and  $C_{n\beta}$ , are then obtained directly with equations 4.22 through 4.24:

$$C_{Y\beta} = \frac{C_Y}{\Delta\beta^\circ} * \frac{180}{\pi} \text{ per radian} \quad 4.22$$

$$C_{l\beta} = \frac{C_l}{\Delta\beta^\circ} * \frac{180}{\pi} \text{ per radian} \quad 4.23$$

$$C_{n\beta} = \frac{C_n}{\Delta\beta^\circ} * \frac{180}{\pi} \text{ per radian} \quad 4.24$$

It should be noted that the CMARC wind axis is modeled with x-aft and z-up, vice x-forward and z-down for the flight dynamics stability axis. Care must be taken to reverse the signs of the appropriate coefficients to convert from the CMARC wind axis to the flight dynamics stability axis system.

Static lateral-directional stability derivatives obtained from CMARC are presented in Table 4.9. For comparison three other sets of data are also presented. The first comes from classical analysis using methods from Roskam [Ref. 12]. The second set comes from estimates based on data recorded from flight-test sideslip maneuvers, published by Papageorgio in Ref. [2]. The third set comes from parameter estimation, by Engdahl, based on dynamic flight-test maneuvers.

METHOD	CONFIGURATION <sup>1</sup>	STATIC LAT-DIR PARAMETERS		
		$C_{Y\beta}$ (per rad)	$C_{l\beta}$ (per rad)	$C_{n\beta}$ (per rad)
CMARC Panel Code	Wing/Fuselage + Horz/Vert Stabs	-0.249	-0.063	0.063
Classical Design <sup>2</sup>	Wing/Fuselage/Vert Tail	-0.511	-0.055	0.051
Flight Test <sup>3</sup>	Flying Aircraft	-0.700	-0.053	0.057
Parameter Estimation <sup>4</sup>	Flying Aircraft	-0.987	-0.094	0.176
	C-172 <sup>5</sup>	-0.310	-0.089	0.065

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6''$  from bottom of fuselage.

2) Classical design calculations by Roskam's methods, after Ref. [12].

3) Flight test results from steady heading sideslip, from Ref. [2]

4) Parameter estimation from flight test data by Engdahl.

5) C-172 data from Ref. [12].

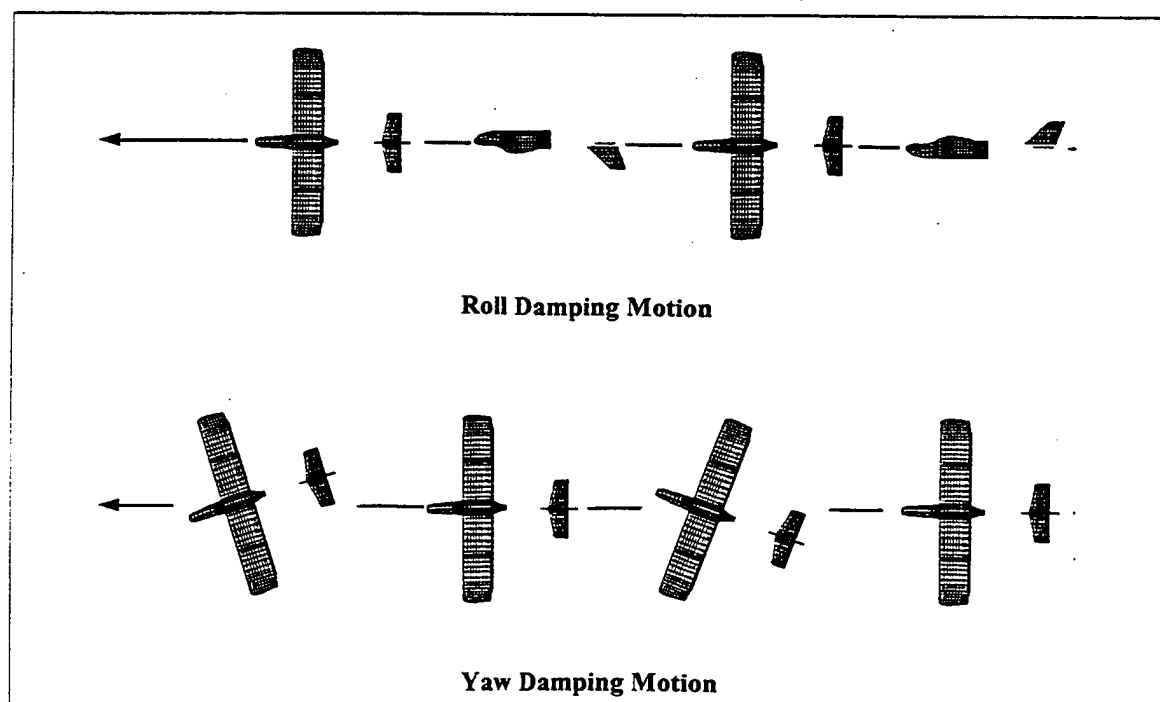
**Table 4.9 Comparison of FROG UAV Static Lateral-Directional Stability Derivatives.**

CMARC produced weak results for the  $C_{Y\beta}$  side force derivative. A large component of  $C_{Y\beta}$ , approximately 60%, comes from the fuselage. Side forces are not modeled well by the potential flow solution. In addition, the engine pylon and pod are left off the model due to problems with their wakes impacting the vertical tail. They most likely provide a significant contribution to side force.

CMARC results for weathercock stability,  $C_{n\beta}$ , and dihedral effect,  $C_{l\beta}$ , show close correlation to the classical calculations. However, dynamic parameter analysis indicates a considerably higher value for both derivatives. The parameter estimation most likely captures the additional dynamic pressure over the vertical stabilizer from prop wash. As with the longitudinal solutions, an attempt should be made to model the propeller disk with a normal velocity distribution.

***b. Lateral-Directional Damping Derivatives***

As with the static case, the dynamic solutions are run with separate wing/fuselage and vertical/horizontal stabilizer models. The solutions are summed through superposition. Figure 4.17 shows the two angular motions selected to develop the lateral-directional rate-damping derivatives. The  $\beta$ -dot terms are generally considered to be small. As a result, the sideways plunging motion test case is not run. Yaw rate-damping is obtained directly from the oscillating yawing motion without the requirement to subtract  $\beta$ -dot effects. Yawing motion is conducted at a frequency of  $2\pi$  rad/s, which equates to a reduced frequency of  $k=0.369$  for this configuration and trim airspeed.



**Figure 4.17 Aircraft Motion for the Determination of Roll and Yaw damping.**

The roll axis is de-coupled from both angle-of-attack and sideslip. Therefore, roll damping can be obtained directly from a constant rolling motion, as illustrated in Figure 4.17. For the FROG study a roll rate of 20°/sec is selected. Initially a lower roll rate of 5°/sec was used. However, the lower rate produced small values of both side force and yawing moment. A higher roll rate prevented machine resolution from becoming a factor in data reduction. The User Guide in Appendix A provides a more detailed description of the techniques used to gather the dynamic lateral-directional derivatives.

The roll damping stability terms are presented in Table 4.10. Traditional design calculations from Roskam [Ref. 12] were completed for comparison to CMARC and flight-test results. In addition, C-172 data is also presented. CMARC roll damping,  $C_{lp}$ , is 50% higher than classical results, but right in line with parameter estimation. CMARC adverse yaw due to roll rate,  $C_{np}$ , is approximately one fourth that obtained from either classical calculations or parameter estimation. Of note, CMARC does capture side force due to roll rate. This term is difficult to obtain from classical techniques and is usually assumed to be negligible.

METHOD	CONFIGURATION <sup>1</sup>	ROLL RATE TERMS		
		$C_{yp}$ (per rad)	$C_{lp}$ (per rad)	$C_{np}$ (per rad)
CMARC Panel Code	Wing/Fuselage + Horz/Vert Stabs	0.05	-0.452	-0.022
Classical Design <sup>2</sup>	Wing/Fuselage/Vert Tail	0	-0.300	-0.072
Parameter Estimation <sup>3</sup>	Flying Aircraft	0	-0.448	-0.108
	C-172 <sup>4</sup>	-0.037	-0.47	-0.03

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6"$  from bottom of fuselage.

2) Classical design calculations by Roskam's methods, after Ref. [12].

3) Parameter estimation from flight test data by Engdahl.

4) C-172 data from Ref. [12].

**Table 4.10 Comparison of FROG UAV Roll Rate Stability Derivatives.**

The yaw rate-damping terms are presented in Table 4.11. Traditional design calculations from Roskam [Ref. 12] are presented for comparison to CMARC and flight-test results. C-172 data is also listed. CMARC does an excellent job of predicting yaw damping. Yaw damping,  $C_{nr}$ , directly matches the result from parameter estimation. CMARC underestimates roll moment due to yaw rate,  $C_{lr}$ , by 25 to 40 percent. And, side force due to yaw rate,  $C_{Yr}$ , is overestimated by a factor of three compared to the parameter estimation model. No explanation is readily available to explain these errors.

METHOD	CONFIGURATION <sup>1</sup>	YAW RATE TERMS		
		$C_{Yr}$ (per rad)	$C_{lr}$ (per rad)	$C_{nr}$ (per rad)
CMARC Panel Code	Wing/Fuselage + Horz/Vert Stabs	0.337	0.121	-0.121
Classical Design <sup>2</sup>	Wing/Fuselage/Vert Tail	0.140	0.168	-0.076
Parameter Estimation <sup>3</sup>	Flying Aircraft	0.110	0.208	-0.121
	C-172 <sup>4</sup>	0.210	0.096	-0.099

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6''$  from bottom of fuselage.

2) Classical design calculations by Roskam's methods, after Ref. [12].

3) Parameter estimation from flight test data by Engdahl.

4) C-172 data from Ref [12].

**Table 4.11 Comparison of FROG UAV Yaw Rate Stability Derivatives.**

**c. Lateral-Directional Control-Power Derivatives**

Aileron and rudder control-power derivatives are presented in Tables 4.12 and 4.13. Classical design calculations are performed using equations 4.25 through 4.30 from Roskam [Ref. 15]:

$$C_{Y\delta_r} = \frac{C_{L_{\alpha_v}}}{C_{L_{\alpha_v}}} C_{l_{\delta_r}} K_b \frac{S_v}{S} \quad 4.25$$

$$C_{l_{\delta r}} = C_{Y_{\delta r}} \frac{(Z_v \cos \alpha - l_v \sin \alpha)}{b} \quad 4.26$$

$$C_{n_{\delta r}} = -C_{Y_{\delta r}} \frac{(l_v \cos \alpha - Z_v \sin \alpha)}{b} \quad 4.27$$

$$C_{Y_{\delta a}} \approx \text{small} \quad 4.28$$

$$C_{n_{\delta a}} = K * C_L * C_{l_{\delta a}} \quad 4.29$$

$$C_{l_{\delta a}} = |\alpha_{\delta a}| * \frac{C_{l_{\alpha}}}{2\pi} \left( \frac{C'_{l_{\delta a}}}{\kappa} \right) \quad 4.30$$

where  $C_{Y_{\delta F}}$ ,  $\alpha_{\delta}$ ,  $\kappa$  and  $(C'_{l_{\delta a}}/\kappa)$  are empirical values from charts in Roskam [Ref. 15]. Additionally, flight-test parameter analysis and C-172 data are provided for comparison.

METHOD	CONFIGURATION <sup>1</sup>	AILERON CONTROL POWER		
		$C_{Y_{\delta a}}$ (per rad)	$C_{l_{\delta a}}$ (per rad)	$C_{n_{\delta a}}$ (per rad)
CMARC Panel Code	Blended Wing-Fuselage/Horz/Vert Tails	-0.021	0.194	-0.0121
Classical Design <sup>2</sup>	Wing/Fuselage/Vert Tail	0	0.213	-0.0236
Parameter Estimation <sup>3</sup>	Flying Aircraft	0	0.239	-0.0261
	C-172 <sup>4</sup>	0	0.178	-0.053

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6''$  from bottom of fuselage.

2) Classical design calculations by Roskam's methods, after Ref. [12].

3) Parameter estimation from flight test data by Engdahl.

4) C-172 data from Ref. [12].

**Table 4.12 Comparison of FROG UAV Aileron Control-Power Derivatives.**

In general, CMARC provides aileron control-power estimates in the correct direction and same order of magnitude as both the classical and parameter estimation techniques. Aileron roll control-power shows excellent correlation to both methods. However, CMARC under-estimates adverse yaw due to aileron deflection,  $C_{n\delta a}$ , by approximately 50%. Yawing moment due to roll rate,  $C_{np}$ , is also underestimated by a similar margin. An investigation into the source of CMARC inaccuracies in the modeling of adverse yaw due to aileron deflection and roll rate is warranted.

The rudder control-power derivatives obtained with CMARC show good correlation to classical design techniques. Side force due to rudder deflection,  $C_{Y\delta r}$ , is 15% greater than classical calculations but closely matches flight-test results. For both  $C_{n\delta r}$  and  $C_{l\delta r}$ , CMARC estimates fall between classical calculations and parameter estimation results. The stronger rudder control-power observed in the parameter estimation model is most likely due to the capturing of prop wash effects.

METHOD	CONFIGURATION <sup>1</sup>	RUDDER CONTROL POWER		
		$C_{Y\delta r}$ (per rad)	$C_{l\delta r}$ (per rad)	$C_{n\delta r}$ (per rad)
CMARC Panel Code	Blended Wing-Fuselage/Horz/Vert Tails	0.0928	0.0040	-0.0453
Classical Design <sup>2</sup>	Wing/Fuselage/Vert Tail	0.081	0.0056	-0.0341
Parameter Estimation <sup>3</sup>	Flying Aircraft	0.093	0.0004	-0.0785
	C-172 <sup>4</sup>	0.187	0.015	-0.0657

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6"$  from bottom of fuselage.

2) Classical design calculations by Roskam's methods, after Ref. [12].

3) Parameter estimation from flight test data by Engdahl.

4) C-172 data from Ref [12].

**Table 4.13 Comparison of FROG UAV Rudder Control-Power Derivatives.**

### 3. Summary of CMARC Stability Derivative Analysis

Table 4.14 lists the complete FROG aerodynamic model obtained from CMARC for the trim condition. In summary, CMARC produces reasonably accurate stability derivatives for an initial aerodynamic model. The greatest difficulty is encountered modeling side force due to sideslip and roll rate. The potential flow solution from CMARC fails to adequately capture the side force on the fuselage. Improved fidelity might be obtained by modeling fuselage flow separation with wake separation lines. CMARC also underestimates yawing moment due to roll rate and aileron deflection by large margins.

LONGITUDINAL		LATERAL-DIRECTIONAL	
Derivative	Value	Derivative	Value
$C_L$	0.4295	$C_{Y\beta}^I$	-0.2493
$C_D$	0.065	$C_{l\beta}$	-0.0630
$C_{L\alpha}$	4.845	$C_{n\beta}$	0.6300
$C_{D\alpha}$	0.2664	$C_{Yp}$	0.0488
$C_{M\alpha}$	-0.4126	$C_{lp}$	-0.4514
$C_{L\dot{\alpha}}$	1.420	$C_{np}$	-0.0220
$C_{M\dot{\alpha}}$	-6.264	$C_{Yr}$	0.3370
$C_{Lq}$	6.862	$C_{lr}$	0.1210
$C_{Dq}$	0	$C_{nr}$	-0.1210
$C_{Mq}$	-11.78	$C_{Y\dot{r}}$	0.0928
$C_{L\delta e}$	0.4378	$C_{l\delta r}$	0.0040
$C_{D\delta e}$	0.0092	$C_{n\delta r}$	-0.0453
$C_{M\delta e}$	-1.199	$C_{Y\delta a}$	-0.0206
		$C_{l\delta a}$	0.1943
		$C_{n\delta a}$	-0.0121

Table 4.14 Summary of CMARC Stability Derivatives for the NPS FROG UAV.

## F. COMPARISON OF DYNAMIC AERODYNAMIC MODELS

This section will discuss the dynamic response of the FROG UAV using the CMARC generated aerodynamic model. Specifically, modal frequency and damping are obtained through eigenvalue analysis. Elevator, aileron and rudder control response is found using a linearized state-equation model. Results are compared to the classical design and parameter estimation models.

Dimensional stability derivatives are placed into linearized 4x4 models as outlined by Schmidt in Ref. [14]. The short-period and long-period modes are obtained using the MATLAB eigenvalue decomposition routine. In a similar manner, the lateral-directional plant matrix yields the roll, spiral and Dutch-roll modes. Dynamic response due to step and doublet control inputs is obtained by assembling the complete linear system. This paper uses control deflection sign convention consistent with Figure 4.9 from Ref. [14]. The MATLAB "lsim" command produces the time based output of the linear system. MATLAB is used to plot the dynamic response.

### 1. Longitudinal Dynamics

#### *a. Longitudinal Dynamic Modes*

The longitudinal response of an aircraft can be reduced to a series of four, first-order differential equations. They are typically written in matrix form based on the state variables  $u/V$ ,  $\alpha$ ,  $q$  and  $\theta$ . The linearized state-equations, in matrix form as developed by Schmidt in Ref. [14], are listed in equations 4.31 to 4.37:

$$\{\dot{x}\} = [A]\{x\} + \{B\}\delta_e \quad 4.31$$

$$\{x\} = [u/V \quad \alpha \quad q \quad \theta]^T \quad 4.32$$

$$[A] = [I_n]^{-1} [A_n] \quad 4.33$$

$$\{B\} = [I_n]^{-1} \{B_n\} \quad 4.34$$

$$[A_n] = \begin{bmatrix} VX_u & X_\alpha & 0 & -g \cos \Theta_0 \\ VZ_u & Z_\alpha & (V + Z_q) & -g \sin \Theta_0 \\ VM_u & M_\alpha & M_q & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad 4.35$$

$$\{B_n\} = [X_{\delta e} \quad Z_{\delta e} \quad M_{\delta e} \quad 0]^T \quad 4.36$$

$$[I_n] = \begin{bmatrix} V & 0 & 0 & 0 \\ 0 & (V - Z_\dot{\alpha}) & 0 & 0 \\ 0 & -M_{\dot{\alpha}} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \text{Inertial matrix} \quad 4.37$$

The non-dimensional stability derivatives generated by CMARC are converted to dimensional derivatives through the transformations listed in Table 4.15. Dimensional derivatives are more convenient because they will lead to time histories being expressed in seconds and frequency in rad/s. The MATLAB script "froguav.m" in Appendix D is used to automate these calculations.

The linearized, longitudinal, state-equation is given by equation 4.31. Note that the plant and control matrices are obtained by pre-multiplying by  $[I_n]^{-1}$ . The eigenvalues of the plant matrix,  $[A]$ , yield the longitudinal dynamic modes. The eigenvalues are obtained from the MATLAB script "froguav.m" listed in Appendix D. The results are presented in Table 4.16.

Term	Description	Units
$X_u$	$-\frac{QS}{mV}(2C_D + M\frac{\partial C_D}{\partial M})$	$s^{-1}$
$X_\alpha$	$\frac{QS}{m}(C_L - \frac{\partial C_D}{\partial \alpha})$	$ft-s^{-2}$
$X_{\dot{\alpha}}$	$-\frac{QS}{m}\left(\frac{c}{2V}\right)\frac{\partial C_D}{\partial(\dot{\alpha}c/2V)}$	$ft-s^{-1}$
$X_q$	$-\frac{QS}{m}\left(\frac{c}{2V}\right)\frac{\partial C_D}{\partial(qc/2V)}$	$ft-s^{-1}$
$X_\delta$	$-\frac{QS}{m}\frac{\partial C_D}{\partial \delta}$	$ft-s^{-2}$
$Z_u$	$-\frac{QS}{mV}(2C_L + M\frac{\partial C_L}{\partial M})$	$s^{-1}$
$Z_\alpha$	$-\frac{QS}{m}(C_D + \frac{\partial C_L}{\partial \alpha})$	$ft-s^{-2}$
$Z_{\dot{\alpha}}$	$-\frac{QS}{m}\left(\frac{c}{2V}\right)\frac{\partial C_L}{\partial(\dot{\alpha}c/2V)}$	$ft-s^{-1}$
$Z_q$	$-\frac{QS}{m}\left(\frac{c}{2V}\right)\frac{\partial C_L}{\partial(qc/2V)}$	$ft-s^{-1}$
$Z_\delta$	$-\frac{QS}{m}\frac{\partial C_L}{\partial \delta}$	$ft-s^{-2}$
$M_u$	$\frac{QS c}{I_y V}\frac{\partial C_m}{\partial M}$	$ft-s^{-1}$
$M_\alpha$	$\frac{QS c}{I_y}\frac{\partial C_m}{\partial \alpha}$	$s^{-2}$
$M_{\dot{\alpha}}$	$\frac{QSC}{I_y}\left(\frac{c}{2V}\right)\frac{\partial C_m}{\partial(\dot{\alpha}c/2V)}$	$s^{-1}$
$M_q$	$\frac{QSC}{I_y}\left(\frac{c}{2V}\right)\frac{\partial C_m}{\partial(qc/2V)}$	$s^{-1}$
$M_\delta$	$\frac{QS c}{I_y}\frac{\partial C_m}{\partial \delta}$	$s^{-2}$

**Table 4.15 Dimensional Longitudinal Stability Derivatives from Ref. [14].**

METHOD	CONFIGURATION <sup>1</sup>	LONGITUDINAL DYNAMIC MODES			
		Short-Period		Phugoid	
		$\omega_n$ (rad/s)	$\zeta$	$\omega_n$ (rad/s)	$\zeta$
CMARC Panel Code	Wing/Fuselage/Horiz Tail	5.15	0.909	0.358	0.136
Classical Design <sup>2</sup>	Wing/Horiz Tail - $\delta\epsilon/\delta\alpha=0.40$	5.90	0.734	0.407	0.110
Parameter Estimation <sup>3</sup>	Flying Aircraft	4.67	0.770	0.397	0.101
	C-172	6.027	0.685	0.181	0.116

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6"$  from bottom of fuselage.

2) Classical design calculations, after Ref. [12].

3) Classical model from Papageorgio [Ref. 2] as modified through parameter estimation from flight test data by Engdahl.

4) C-172 data from Ref. [12].

**Table 4.16 Comparison of FROG UAV Dynamic Longitudinal Modes.**

Table 4.16 summarizes the longitudinal dynamic modes. The CMARC aerodynamic model provides a better estimate of short-period frequency than the classical design technique. The CMARC short-period frequency is 10% faster than that observed from parameter analysis and damping is 21% higher. The high damping in all three models will produce nearly deadbeat results. The CMARC phugoid, or long period, is 10% slower than observed from flight-test with 40% more damping. Although, it must be pointed out that it is difficult to accurately capture the phugoid mode in flight-test. This is due to difficulty the external pilot has in accurately maintaining wings level trim during the extended period required for capturing phugoid data. Overall, the CMARC aerodynamic model produces satisfactory short-period and phugoid modal data for the development of closed-loop flight controls. Of note, CMARC provides a more accurate prediction of the important short-period natural frequency. The larger error in phugoid frequency is less important to the design of a closed loop controller.

***b. Longitudinal Dynamic Response to Control Input***

Following dynamic mode analysis, the response to an elevator step-input and a doublet-input is modeled using MATLAB. Dynamic response for the CMARC, classical and parameter analysis models are overlaid for comparison. The linear system is set up using the MATLAB script "froguav.m" in Appendix D. The "lsim" command outputs the time-based response from a time-based control input vector. A  $-2^\circ$  (TEU) elevator step-input is selected to keep the response in the linear region. A  $5^\circ$  elevator doublet with a 1.2 second period is used to excite the short-period mode. The selected doublet period closely matches the short-period mode. Dynamic response is displayed in Figures 4.18 and 4.19.

The FROG UAV response to a  $-2^\circ$  (TEU) step elevator input is displayed in Figure 4.18. All three aerodynamic models are presented for comparison. The model adjusted by parameter analysis shows a much larger response than either the CMARC or classical design models. The CMARC model produces a final pitch angle change after 4 seconds of  $35^\circ$  versus  $45^\circ$  for the flight-tested model. On closer review, it is noted the  $C_{m\delta e} = -1.199$  from CMARC is considerably less than the  $C_{m\delta e} = -1.621$  from flight-test. It should be noted that the parameter estimation model compensates for real world factors including; air load distortions, sensor measurement errors and prop wash. In other words, the CMARC model assumes uniform displacement and perfect sensors while the flight-test model is empirically fit to a measured response.

The response to a  $5^\circ$  elevator doublet is displayed in Figure 4.19. All three models show a similar frequency and a high degree of damping. As expected, the parameter estimation model produces a larger response. The magnitude of the CMARC response is approximately two thirds of that observed from the flight-test model. Again, this is due to the much larger value of  $C_{m\delta e}$  obtained from empirically fitting the parameter estimation model to observed aircraft response. Modeling prop wash with CMARC should produce improved results.

In summary, the CMARC aerodynamic model showed satisfactory longitudinal control response in frequency and damping. It is recommended that  $C_{m\delta e}$  be adjusted to increase elevator response.

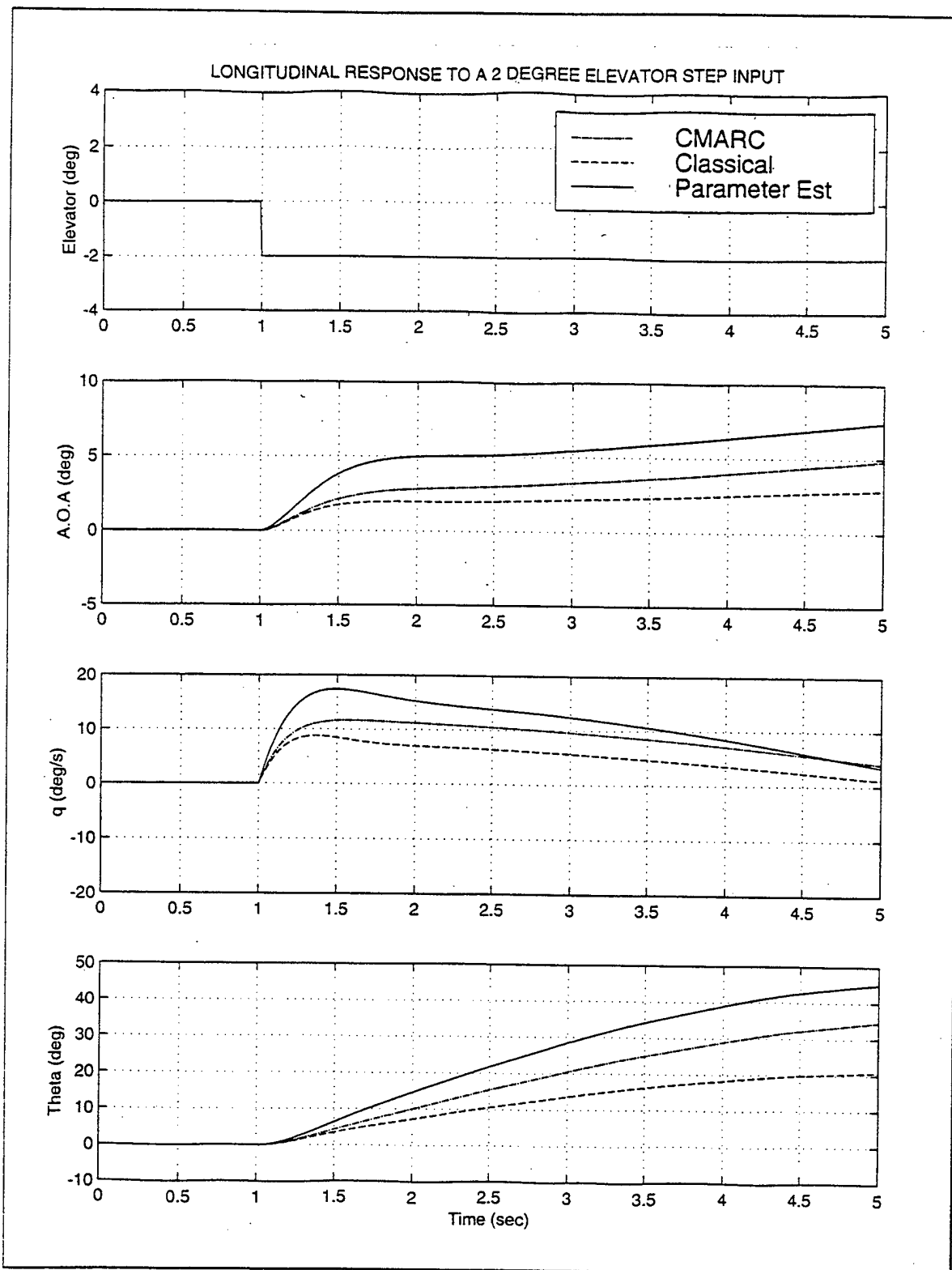
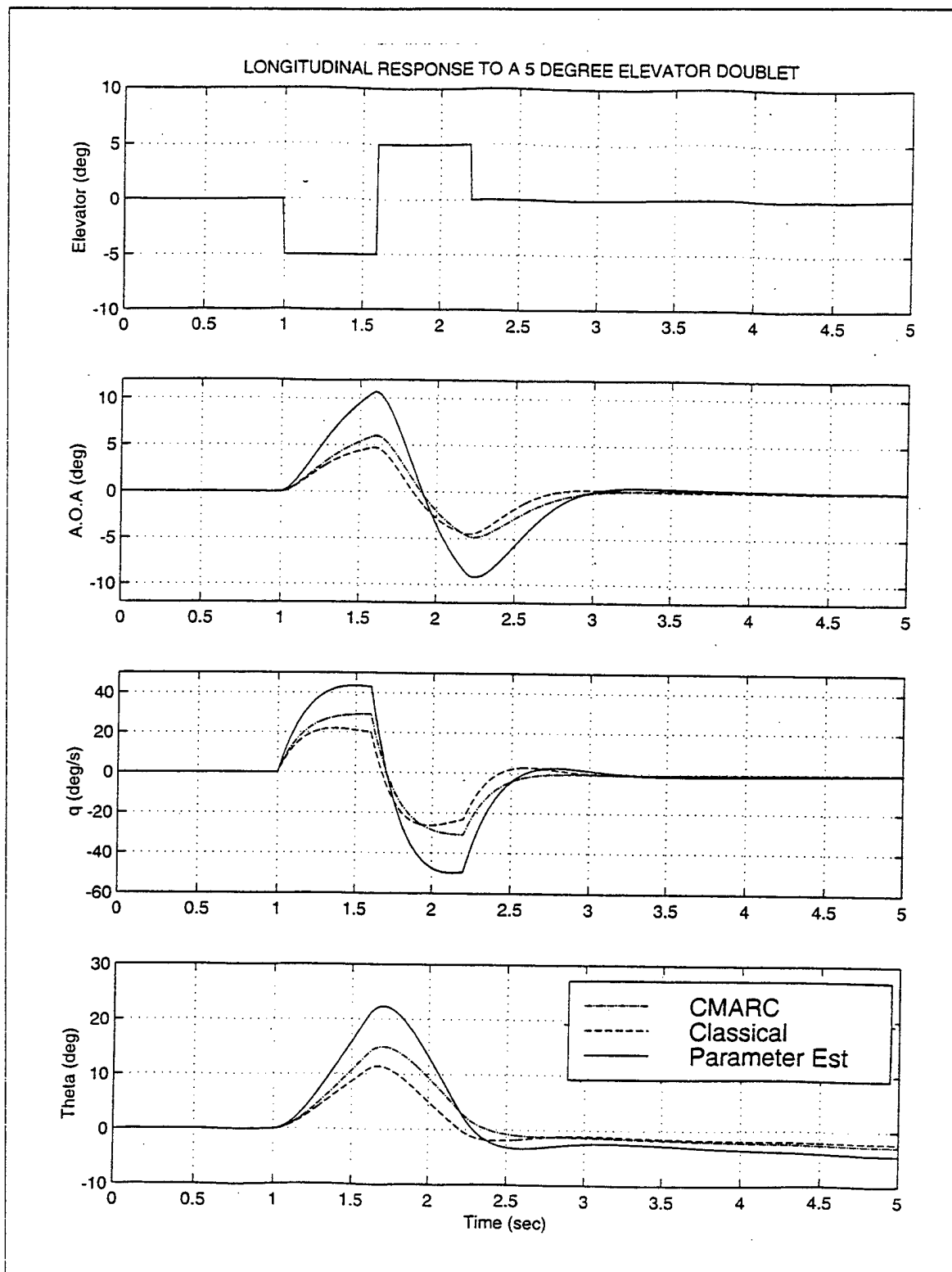


Figure 4.18 FROG UAV Dynamic Response to a -2° (TEU) Elevator Step Input.



**Figure 4.19 FROG UAV Dynamic Response to a 5° Elevator Doublet.**

## 2. Lateral-Directional Dynamics

### a. Lateral-Directional Dynamic Modes

The lateral-directional response of an aircraft can also be reduced to a series of four first-order differential equations. They are typically written in matrix form based on the state-variables  $\beta$ ,  $p$ ,  $\phi$ , and  $r$ . The linearized state-equations in matrix form as developed by Schmidt in Ref. [14] are listed in equations 4.38 to 4.44:

$$\{\dot{x}\} = [A]\{x\} + \{B\}\delta_{a/r} \quad 4.38$$

$$\{x\} = [\beta \quad p \quad \phi \quad r]^T \quad 4.39$$

$$[A] = [I_n]^{-1} [A_n] \quad 4.40$$

$$\{B\} = [I_n]^{-1} \{B_n\} \quad 4.41$$

$$[A_n] = \begin{bmatrix} Y_\beta & Y_p & g \cos \Theta_0 & (Y_r + V) \\ L_\beta & L_p & 0 & L_r \\ 0 & 1 & 0 & 0 \\ N_\beta & N_p & 0 & N_r \end{bmatrix} \quad 4.42$$

$$\{B_n\} = \begin{bmatrix} Y_{\delta a} & L_{\delta a} & 0 & N_{\delta a} \\ Y_{\delta r} & L_{\delta r} & 0 & N_{\delta r} \end{bmatrix}^T \quad 4.43$$

$$[I_n] = \begin{bmatrix} V & 0 & 0 & 0 \\ 0 & (V - Z_{\dot{\alpha}}) & 0 & 0 \\ 0 & -M_{\dot{\alpha}} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \text{Inertial matrix} \quad 4.44$$

As with the longitudinal axis, the stability derivatives generated by CMARC are dimensionless. However, it is more convenient to use dimensional derivatives. They will lead to time histories being expressed in seconds and frequency in rad/s. The lateral-directional stability derivatives are turned into dimensional derivatives through the transformations listed in Table 4.17 from Ref. [14]. The MATLAB script "foguav.m" in Appendix D is used to automate these calculations.

Term	Description	Units
$Y_\beta$	$\frac{QS}{m} \frac{\partial C_y}{\partial \beta}$	$\text{ft-s}^{-2}$
$Y_p$	$\frac{QS}{m} \left( \frac{b}{2V} \right) \frac{\partial C_y}{\partial (p b/2V)}$	$\text{ft-s}^{-1}$
$Y_r$	$\frac{QS}{m} \left( \frac{b}{2V} \right) \frac{\partial C_y}{\partial (r b/2V)}$	$\text{ft-s}^{-1}$
$Y_\delta$	$\frac{QS}{m} \frac{\partial C_y}{\partial \delta}$	$\text{ft-s}^{-2}$
$L_\beta$	$\frac{QS b}{I_x} \frac{\partial C_l}{\partial \beta}$	$\text{s}^{-2}$
$L_p$	$\frac{QS b}{I_x} \left( \frac{b}{2V} \right) \frac{\partial C_l}{\partial (p b/2V)}$	$\text{s}^{-1}$
$L_r$	$\frac{QS b}{I_x} \left( \frac{b}{2V} \right) \frac{\partial C_l}{\partial (r b/2V)}$	$\text{s}^{-1}$
$L_\delta$	$\frac{QS b}{I_x} \frac{\partial C_l}{\partial \delta}$	$\text{s}^{-2}$
$N_\beta$	$\frac{QS b}{I_z} \frac{\partial C_n}{\partial \beta}$	$\text{s}^{-2}$
$N_p$	$\frac{QS b}{I_z} \left( \frac{b}{2V} \right) \frac{\partial C_n}{\partial (p b/2V)}$	$\text{s}^{-1}$
$N_r$	$\frac{QS b}{I_z} \left( \frac{b}{2V} \right) \frac{\partial C_n}{\partial (r b/2V)}$	$\text{s}^{-1}$
$N_\delta$	$\frac{QS b}{I_z} \frac{\partial C_n}{\partial \delta}$	$\text{s}^{-2}$

**Table 4.17 Dimensional Lateral-Directional Stability Derivatives from Ref. [14]**

The linearized, lateral-directional state-equation is given by equation 4.38. Note that the plant and control matrices are obtained by pre-multiplying by  $[I_n]^{-1}$ . The dimensional derivatives from Table 4.16 populate the linearized 4x4 plant matrix and control matrices. The plant matrix,  $[A]$ , is used to obtain the lateral-directional dynamic modes. The eigenvalues are obtained from MATLAB using the "froguav.m" script in Appendix D. The results are presented in Table 4.18.

METHOD	CONFIGURATION <sup>1</sup>	LATERAL-DIRECTIONAL DYNAMIC MODES			
		Dutch-Roll		Roll	Spiral
		$\omega_n$ (rad/s)	$\zeta$	$\omega_n$ (rad/s)	$\omega_n$ (rad/s)
CMARC Panel Code	Wing/Fuselage Group plus Horiz/Vert Stab Group	2.54	0.13	-3.80	0.000
Classical Design <sup>2</sup>	Wing/Fuselage/Horiz Tail	2.48	0.09	-2.83	0.065
Parameter Estimation <sup>3</sup>	Flying Aircraft	4.27	0.14	-3.97	0.090
	C-172 <sup>4</sup>	3.38	0.20	12.43	0.01

NOTES: 1)  $CG_x=34.5\%$  M.A.C. /  $CG_z=8.6"$  from bottom of fuselage.

2) Classical design calculations after Ref. [12].

3) Classical model from Papageorgio [Ref. 2] as modified through parameter estimation from flight test data by Engdahl.

4) C172 data from Ref. [12].

**Table 4.18 Comparison of FROG UAV Lateral-Directional Dynamic Modes.**

The lateral-directional dynamic modes are summarized in Table 4.18. The CMARC aerodynamic model provides significantly better estimates of frequency and damping than the classical design technique for both the Dutch-roll and roll modes. The CMARC Dutch-roll natural frequency, although better than the classical response, is 40% lower than predicted by parameter estimation. Adjustments should be made to the CMARC aerodynamic model to improve Dutch-roll response.

The primary contributor to the Dutch-roll frequency is weathercock stability,  $C_{n\beta}$ . A review of Table 4.9 shows that  $C_{n\beta}$  obtained from CMARC is considerably less than the value obtained through parameter estimation. One potential source of error is the lack of modeling the increased dynamic pressure due to prop wash. The FROG model should be re-worked to include a prop disk to investigate the ability of CMARC to capture prop wash effects.

The CMARC model predicts a neutral spiral mode. This is most likely due to a combination of equal and opposite  $C_{lr}$  and  $C_{nr}$  ratios. When the  $C_{lr}/C_{nr}$  ratio is changed to -2 (approximately that of the analytical and parameter estimation models), the spiral mode comes out close to the analytical model. The weak roll due to yaw-rate,  $C_{lr}$ , in the CMARC solution seems to be the main source of error in the spiral mode. The value will need to be modified to produce an acceptable spiral response.

#### ***b. Lateral-Directional Dynamic Response to Control Input***

Following dynamic-mode analysis, the response to aileron and rudder inputs is modeled using MATLAB. Dynamic response for the CMARC, classical and parameter-analysis models are overlaid for comparison. The linear system is set up using the MATLAB script "froguav.m" in Appendix D. The "lsim" command outputs the time-based response from a time-based input control vector.

The lateral response to a  $+2^\circ$  (right wing down) step aileron deflection is shown in Figure 4.20. CMARC steady-state roll-rate is less than that predicted by the other two models. This is expected considering the CMARC model has the lowest ratio of aileron control-power to roll-damping. In addition, the side-force terms,  $C_{Yp}$  and  $C_{Y\delta a}$ , modeled by CMARC both fight roll-rate. They are not included in the other models. Perhaps they should be assumed small and set to zero. CMARC does a significantly better job of modeling the Dutch-roll response. The roll-rate and sideslip traces from the classical design model clearly show excess excitation of the Dutch-roll mode. The CMARC model shows a better correlation to the parameter estimation model for Dutch-roll amplitude and damping. As predicted by the eigenvalues, Dutch-roll frequency is slower than the parameter estimation model.

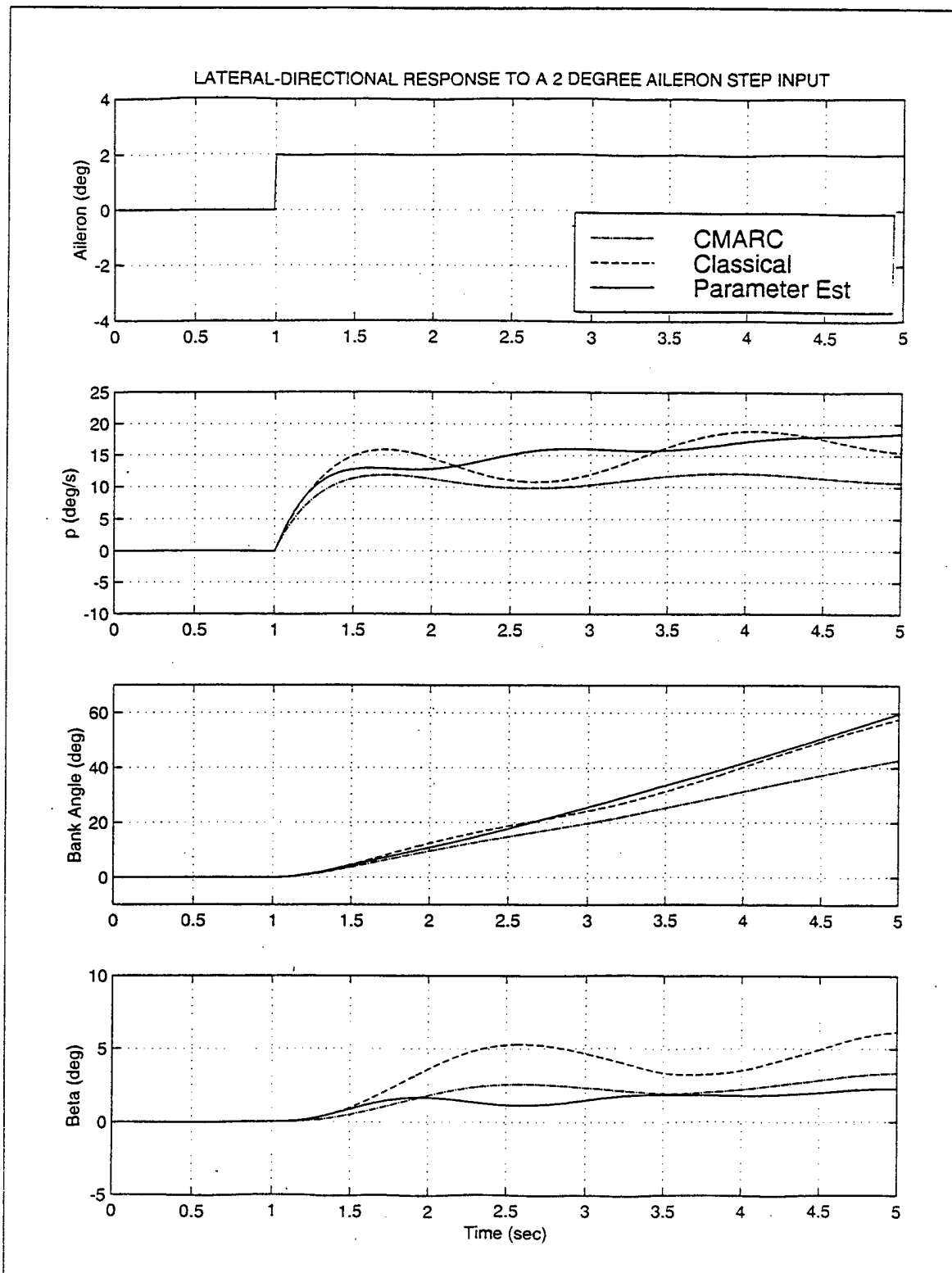
The lateral-directional response to a  $5^\circ$  aileron doublet is shown in Figure 4.21. The 1.5 second period clearly excites the Dutch-roll mode in all three models. As with the step-input response, the CMARC model provides a significantly better match to

Dutch-roll excitation than the classical design model. Amplitude and damping show a close correlation to the parameter estimation model. A lower Dutch-roll frequency is evident in the CMARC sideslip trace.

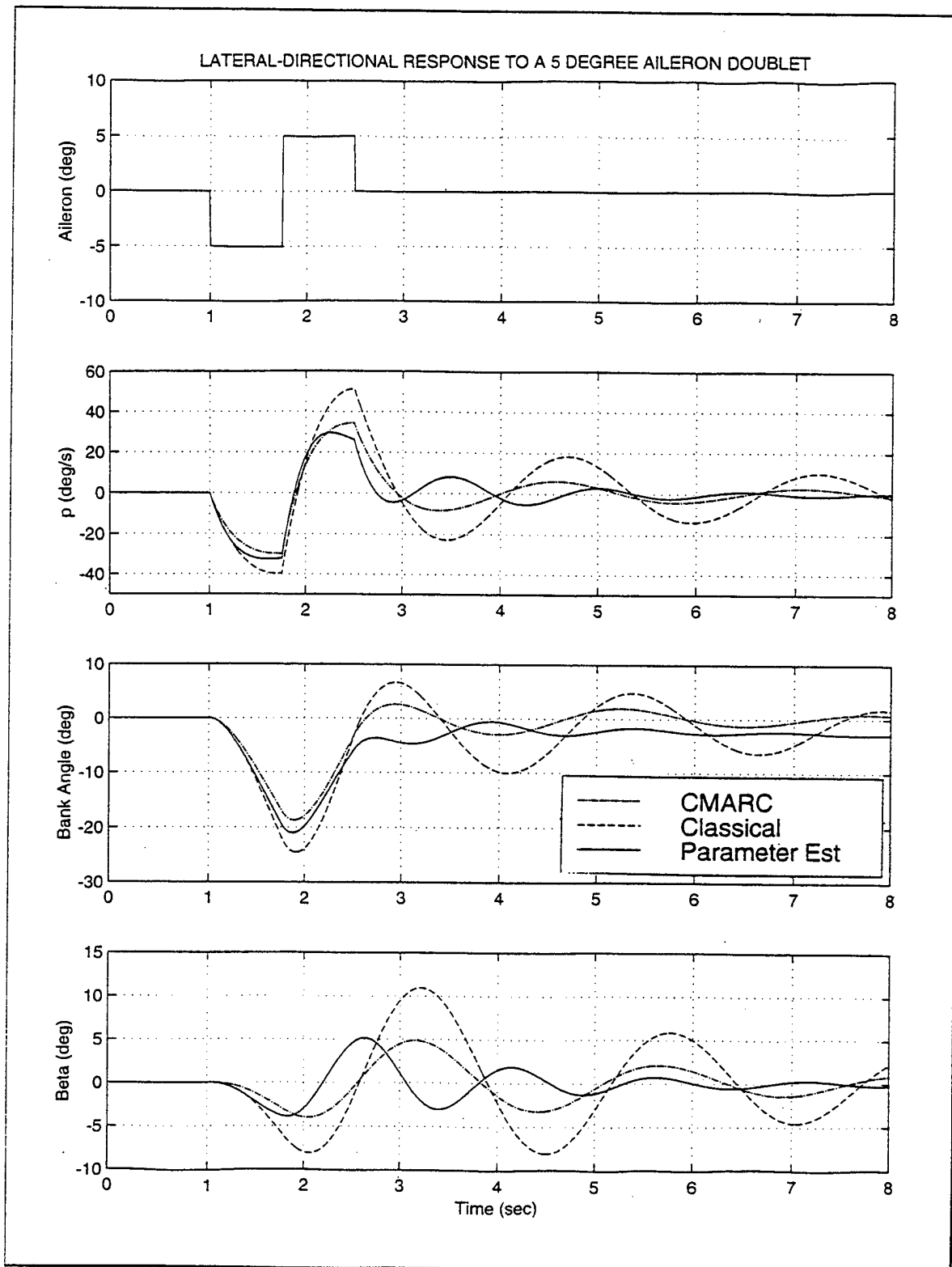
The lateral-directional response to a  $+2^\circ$  (nose left) rudder deflection is shown in Figure 4.22. The CMARC model demonstrates a close match to the classical design model for Dutch-roll frequency and damping. CMARC shows higher sideslip excitation than the classical design model. A slower Dutch-roll frequency is evident in both the CMARC and classical design models.

The lateral-directional response to a  $5^\circ$  rudder doublet deflection is shown in Figure 4.23. Again, the 1.5 second doublet excites the Dutch-roll mode in all three models. CMARC provides a similar response to the classical design model. As expected, Dutch-roll natural frequency is about 40% slower than the parameter estimation model with similar damping.

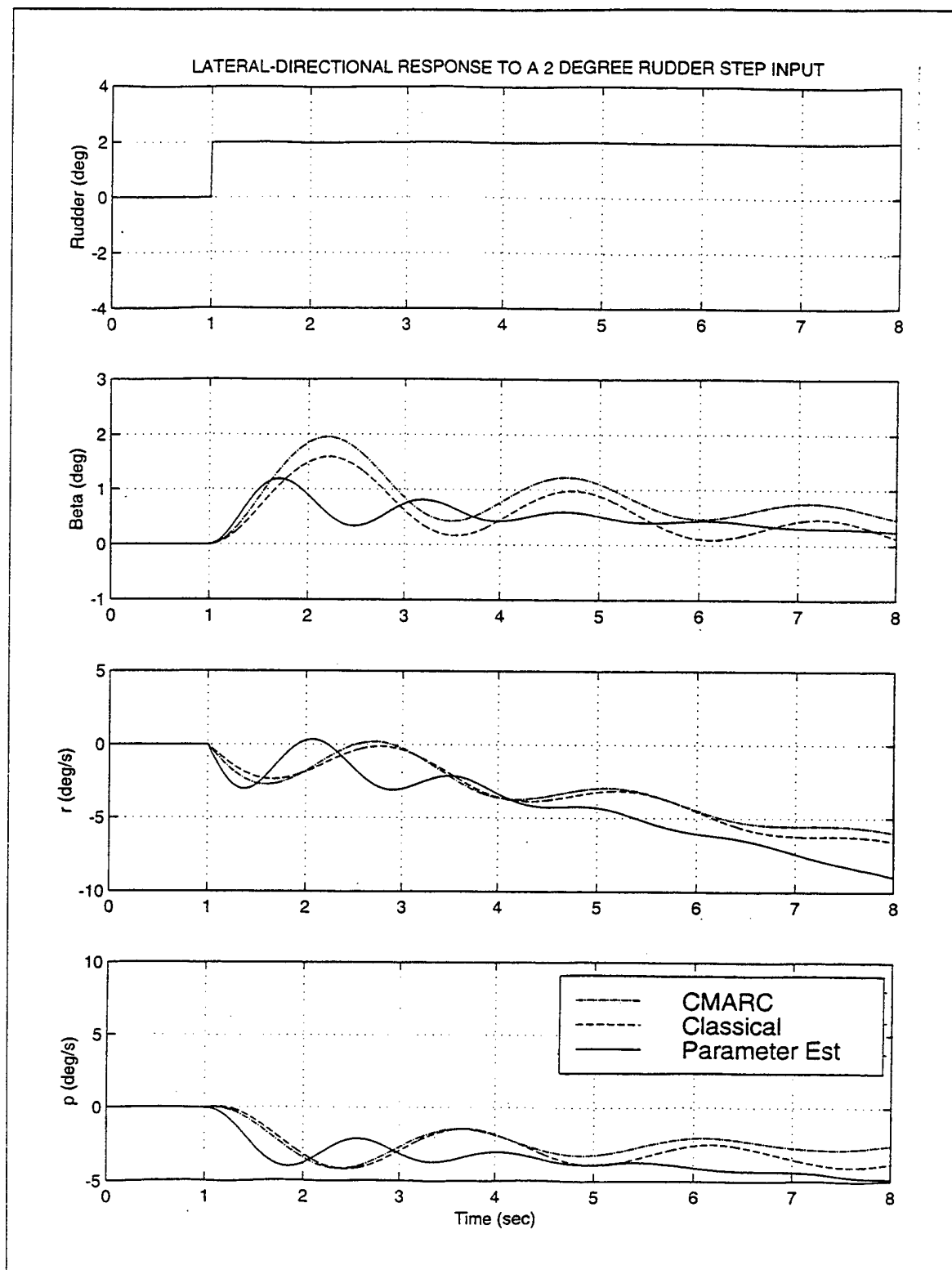
In summary, the CMARC lateral-directional model provides FROG dynamics that are similar to the classical design calculations. However, current CMARC lateral-directional dynamics are not adequate for closed-loop controller or autopilot design. Minor adjustments will be required to better match observed flight characteristics. The lateral-directional model should be modified to include a propeller disk. Higher dynamic pressure over the tail surfaces should provide a stronger  $C_{n\beta}$  derivative and result in faster Dutch-roll frequency. In addition, the FROG model should be adjusted to provide a higher aileron control-power to roll-damping ratio. This modification will improve roll-rate response.



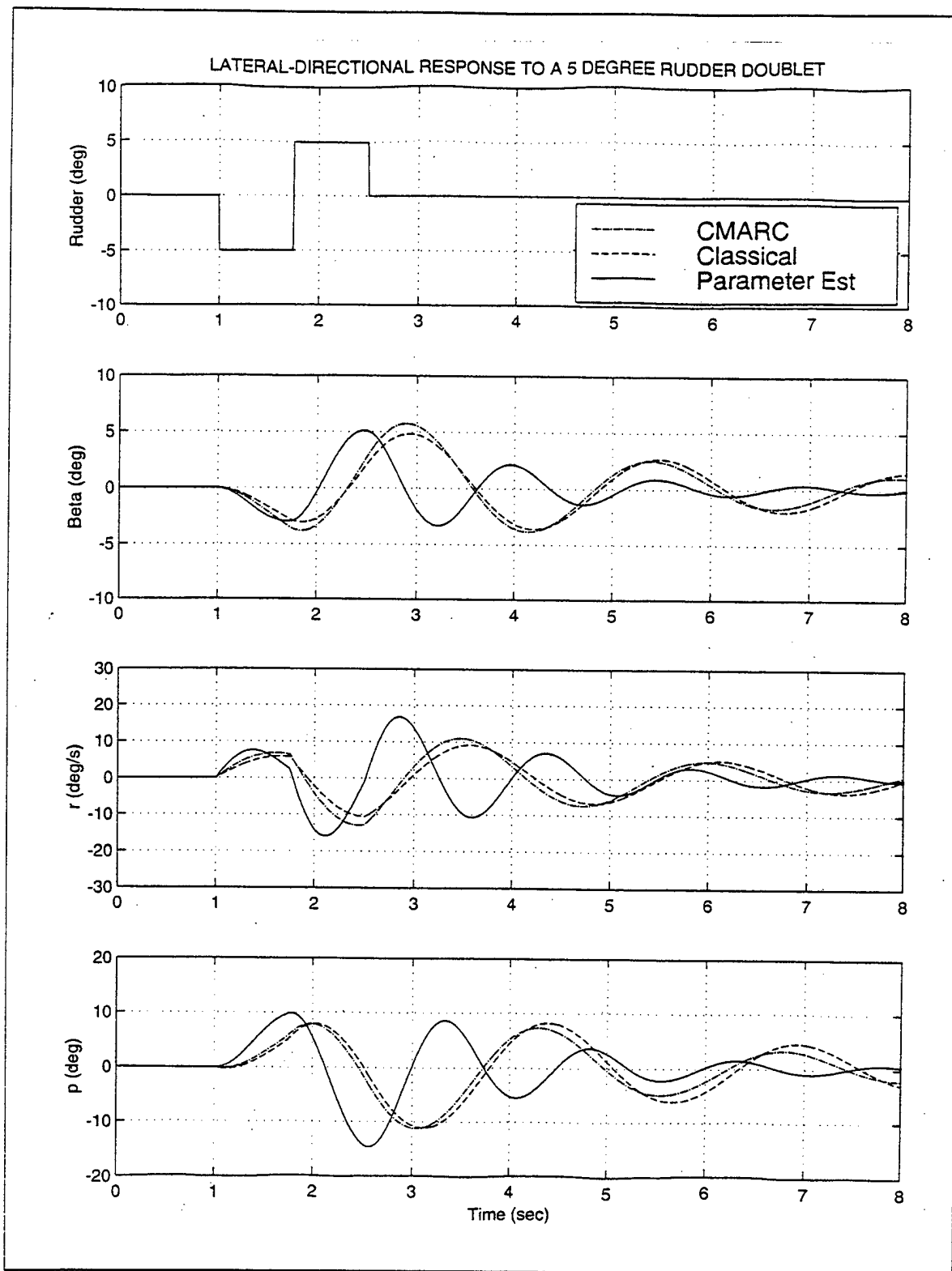
**Figure 4.20 FROG UAV Dynamic Response to a +2° (RWD) Aileron Step Input.**



**Figure 4.21 FROG UAV Dynamic Response to a 5° Aileron Doublet.**



**Figure 4.22 FROG UAV Dynamic Response to a +2° (TEL) Rudder Step Input.**



**Figure 4.23 FROG UAV Dynamic Response to a 5° Rudder Doublet.**

## V. CONCLUSIONS AND RECOMMENDATIONS

CMARC is a DOS personal-computer hosted panel-code adopted from the NASA Ames PMARC code. AeroLogic, Inc., created CMARC by converting PMARC FORTRAN 77 source code into the C language. Significant memory management and command-line enhancements were also added. CMARC solves for inviscid, incompressible flow over complex three-dimensional bodies. Emphasis in this study is placed on expanding the use of CMARC to develop a full aerodynamic model of the Naval Postgraduate School FROG UAV. The CMARC stability derivatives are compared to models derived from classical design calculations and parameter estimation. In addition, pitot-static and angle-of-attack sensor position corrections are obtained through CMARC analysis.

The LOFTSMAN and POSTMARC portions of the Personal Simulation Works software suite are used exclusively for the pre-process modeling and post-process visualization of CMARC files. The LOFTSMAN capability to automatically format and generate CMARC input patches is an enhancing characteristic. Functionality should be added to allow the modeling of wing tip ribs that are not parallel to the aircraft centerline.

POSTMARC is an excellent tool for visualizing CMARC output files. The capability to create streamlines and perform boundary-layer calculations external to CMARC is extremely useful. However, much time could be saved if POSTMARC maintained previous settings and selections following translations, rotations and re-scaling. Additionally, a capability to overlay multiple data types is desired.

CMARC off-body flow-field analysis is useful for both static source and angle-of-attack sensor position corrections. In-flight measurements may be corrected using look-up tables or through curve-fits of CMARC-derived data. Flight testing is recommended for validation of sensor corrections obtained from the CMARC off-body analysis.

For the static longitudinal analysis, CMARC produces accurate values for  $\alpha_{trim}$  and  $C_{M\alpha}$  and a slightly high value of  $C_{L\alpha}$ . Elevator control-power ( $C_{M\delta e}$ ) from CMARC is considerably weaker than the value obtained from parameter estimation. CMARC-derived pitch-damping is stronger than the pitch-damping from both classical design calculations and parameter estimation.

Longitudinal dynamic-mode analysis shows an acceptable match for short-period and long-period frequency and damping. As expected, a lower dynamic response to

elevator control inputs is observed when compared to the parameter estimation model. However, in all cases, the CMARC aerodynamic model demonstrates better dynamic response than the classical design model. A propeller disk should be added to the CMARC model in an attempt to capture prop-wash effects on the horizontal stabilizer and elevator. Increased elevator control-power would provide a better match with observed flight characteristics.

In general, CMARC provides satisfactory lateral-directional derivatives. Roll-damping closely matches the value obtained through parameter estimation. The greatest difficulty encountered is in modeling side-force due to both sideslip and roll-rate. The potential flow solution from CMARC fails to adequately capture the side force on a slender-body fuselage. Additional wakes, placed along separation lines, may improve fuselage side-force prediction.

Dynamic response to rudder control input shows close correlation in amplitude and damping to the parameter estimation model. However, both the CMARC and classical models of the FROG UAV produced a slower Dutch roll frequency. Steady state roll-rate obtained from the CMARC model is somewhat slower than either the classical design or parameter estimation models.

Overall, the CMARC panel code is found to be suitable for aerodynamic modeling of the Naval Postgraduate School FROG UAV. CMARC-derived stability derivatives are sufficiently accurate for incorporation into an initial aerodynamic model. The CMARC aerodynamic model demonstrated better longitudinal dynamic response than the classical design model. Lateral-directional response is similar to that obtained from classical design techniques. Adjustment through comparison with flight-test data is still required to optimize the CMARC model. Future studies should concentrate on improving CMARC modeling of fuselage side force through the addition of separation wake lines. Additionally, the propeller disk should be modeled in an attempt to capture the effects of increased dynamic pressure over the horizontal and vertical tail surfaces.

**APPENDIX A**

**CMARC STABILITY DERIVATIVE USER GUIDE**

**CMARC USER GUIDE**  
**FOR**  
**OBTAINING STABILITY DERIVATIVE DATA**

by

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September 1998

Naval Postgraduate School  
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## A. INTRODUCTION

### 1. CMARC Panel Code and Limitations

CMARC is a PC hosted panel code. The code is useful for gathering aircraft stability data subject to the limitation of inviscid, potential flow solutions. Panel codes assume fully attached flow. Therefore, care must be taken to gather stability data in the linear region of the lift curve slope where separation effects are minimized. The results obtained from CMARC should always be spot checked with classical design calculations.

CMARC and PMARC have been shown to produce functionally equivalent results. The guide describes the use of DOS batch files for automating CMARC data runs on a PC. PMARC, hosted on an SGI machine, will require the use of UNIX batch commands.

### 2. Overview of Obtaining Stability Derivatives with CMARC

An overview of the methods to obtain stability derivatives follows. The detailed description and data reduction methods can be found in the appropriate section of the user guide.

For the static stability derivatives, the CMARC model is run at two different angles-of-attack and one sideslip angle. The static solutions are obtained without control surface deflections. The slopes of the force and moment coefficients are then taken to produce the  $C_{L\alpha}$  and  $C_{m\alpha}$  longitudinal derivatives and the  $C_{Y\beta}$ ,  $C_{l\beta}$  and  $C_{n\beta}$  lateral-directional derivatives.

For the control power derivatives, the model is run at the trim condition with successive elevator, aileron and rudder control deflections. The difference between the results with and without control surface deflections yield the  $C_{L\delta_e}$ ,  $C_{M\delta_e}$  and  $C_{D\delta_e}$  longitudinal and the  $C_{Y\delta_r}$ ,  $C_{l\delta_r}$ ,  $C_{n\delta_r}$ ,  $C_{l\delta_a}$  and  $C_{n\delta_a}$  lateral-directional control power derivatives.

Development of the damping derivatives is not as straight forward. For the dynamic derivatives, motion is enabled around the center of gravity. With motion turned on, it is extremely important to ensure that the global origin and C.G. are co-located. If they are not, a rotation around a specific axis will also create a translation at the C.G.

For the longitudinal damping derivatives, the model is run with oscillating vertical plunging motion to obtain the  $C_L$  and  $C_M$   $\alpha$ -dot terms. The lift and pitching moment coefficients are broken into real (in phase with AOA) and imaginary (out of phase with AOA) components. The imaginary components are due to  $\alpha$ -dot effects. Next, the model is run with oscillating pitch motion to obtain the combined  $\alpha$ -dot and pitch rate terms. Subtracting the  $\alpha$ -dot influence obtained from the plunging motion isolates the pitch rate damping term from the pitch motion.

For the lateral-directional analysis, the  $\beta$ -dot terms are generally negligible. This allows the model to be run with just oscillating roll and yaw motion. As with the longitudinal test case, the imaginary or out of phase component yields the combined  $\beta$ -dot and rate damping data. With the  $\beta$ -dot terms assumed negligible, the oscillating motion yields the  $C_Y$ ,  $C_l$ , and  $C_n$  roll and yaw rate terms directly.

### **3. Coefficient Normalization and Stability Axis System**

CMARC contains built-in functionality to integrate forces and moments over the surface of a body. Forces and moments are automatically normalized into non-dimensional coefficients based on the mean aerodynamic chord, reference wing area, semi-span and center of gravity location in the CMARC BINP9 input line. CMARC outputs coefficients in both the wind and body axes. Of note, CMARC uses the semi-span to normalize rolling and yawing moment coefficients. Most texts on stability and control, including Roskam's "Aircraft Flight Dynamics" and Etkin's "Dynamics of Flight," normalize rolling and yawing moments by span. This user guide will normalize roll and yaw moments by span. Table A.1 summarizes the factors for normalizing moments and angular rates. All rolling and yawing moment coefficients presented in this guide have been normalized with span by dividing the CMARC output by a factor of two. Table A.1 also indicates the characteristic time,  $t^*$ , employed for angle rate data reduction.

In addition to differences in normalizing moments, CMARC uses the typical CFD axes system shown in Figure A.1. This user guide will perform all calculations in the stability axes system as illustrated in Figure A.1. The sign of CMARC roll and yaw moments need to be reversed. The direction for positive control deflections is also shown in Figure A.1. All control surfaces are patched with positive deflections using the convention in Figure A.1.

MOMENTS	NORMALIZING PARAMETER <sup>1</sup>	RATES	CHARACTERISTIC TIME
$L = C_l \bar{q} S b$	$b$	$\hat{p} = \frac{pb}{2u_o}$	$t^* = b/2u_o$
$M = C_m \bar{q} S \bar{c}$	$\bar{c}$	$\hat{r} = \frac{r\bar{c}}{2u_o}$	$t^* = \bar{c}/2u_o$
$N = C_n \bar{q} S b$	$b$	$\hat{r} = \frac{rb}{2u_o}$	$t^* = b/2u_o$

Note: 1) CMARC normalizes roll and yaw coefficients with  $b/2$ .

**Table A.1 Normalized Moment and Rate Equations.**

## **B. MODEL VALIDATION**

### **1. Initial Solution at the Trim Condition**

Once a CMARC model is built up, a reference solution is obtained at the desired trim condition. Initial hand calculations or flight test data can be used to select the estimated cruise angle-of-attack. Use POSTMARC to visualize the reference solution. Check to make sure the pressure distribution is consistent with expected results. Stagnation zones ( $C_p=1$ ) should be evident on the leading and trailing edges of the flight surfaces and aerodynamic bodies. Lower pressure should be observed on the top of lifting surfaces and tip loss should be observed near the wing tips. Wakes should trail from the expected surfaces.

If abnormal pressure distribution is observed, check for inverted panel orientation. This is accomplished by changing the color for positive and negative panel orientations using the "View >> Color" pull-down menu. The default color is white for both orientations. Change the inside to a contrasting color such as red. All panels should face in the positive out direction. If a patch has panels oriented inward, change the orientation of the patch with the "IREV" term in the initial patch definition.

Check that the model is symmetric around the lateral and directional axes with sideslip set to zero. Residual rolling or yawing moment without a control deflection is an indication of an asymmetric model.

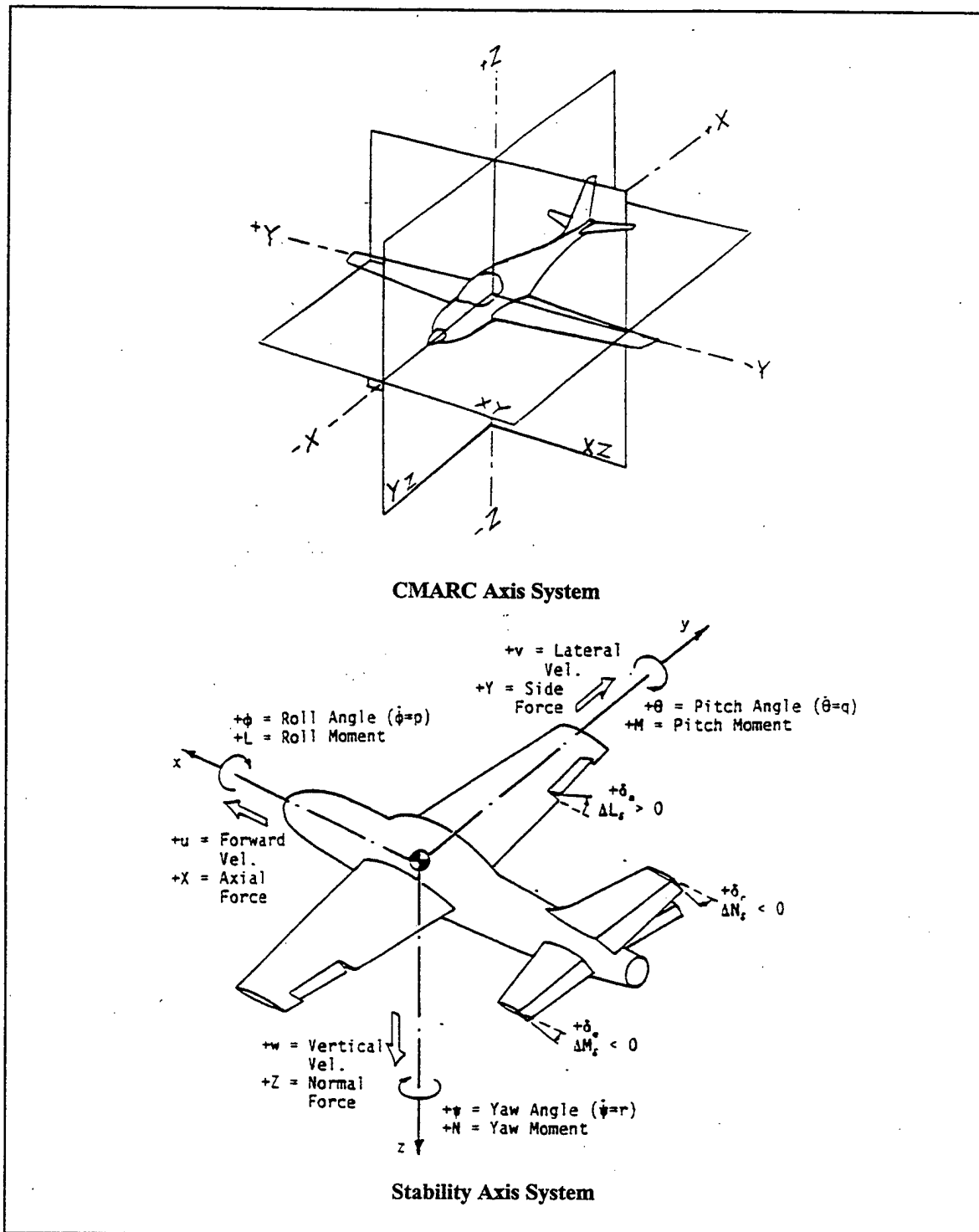


Figure A.1 CMARC CFD Axis System Compared To Stability Axis System. From References [3] and [14] Respectively.

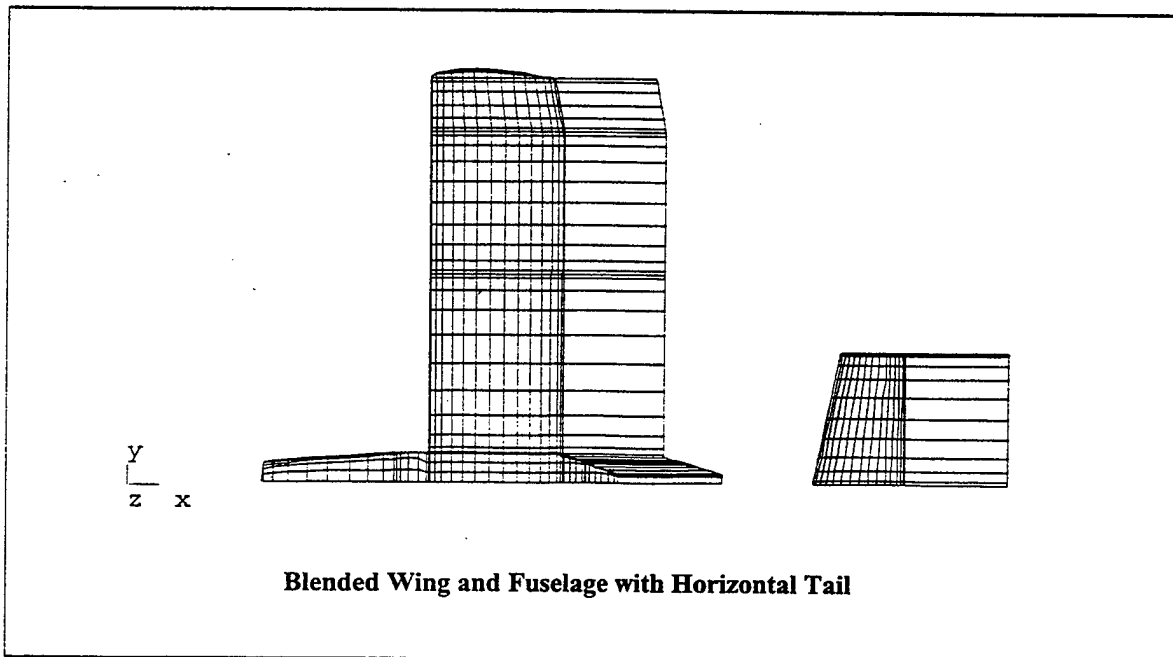
Pitching moment should be checked for a reasonable value. Don't forget to verify that the origin of the global coordinate system is set to the center-of-gravity (C.G.). It is important to remember that the damping derivatives will be obtained by inducing motion around the center-of-gravity. If the C.G. and origin are not collocated, angular motion will generate undesired translation at the C.G.

Next, the lift coefficient from the initial solution is checked to make sure it is in the "ballpark." If a major discrepancy is noted, the input file will have to be checked closely for error. Be sure to check the normalizing factors such as wing area, reference chord and semi-span. If every thing looks good, try increasing or decreasing the angle-of-attack to see if a slight adjustment will bring the lift coefficient in line with the hand calculation. Once the model exhibits symmetry with a reasonable lift distribution, you're ready to start gathering data.

### C. LONGITUDINAL STABILITY DERIVATIVES

This section will describe CMARC methods for the development of longitudinal stability derivatives to include the static, rate damping and control power derivatives. As stated earlier, the results obtained from CMARC should be checked against classical design calculations. The potential flow analysis performed by CMARC does not provide accurate viscous drag values. Total drag can be estimated from the flight test power-off glide ratio or cruise thrust required. If this data is unavailable, then empirical data from publications such as Hoerner's "Fluid Dynamic Drag" can be used to estimate total drag.

For the longitudinal analysis, only half the model is analyzed. This cuts the model size in half, resulting in much quicker solutions. The symmetric calculation mode is selected by setting both  $RSYM=0.0$  and  $IPATSYM=0$  in the CMARC input file. Remove the vertical tail patch if it interferes with wing or fuselage wakes. Figure A.2 shows the FROG model configuration used to find the longitudinal derivatives. A rigid wake is selected that is continuous from wingtip to wingtip. As will be seen in a later section, the vertical tail is added for the lateral-directional solutions. This requires the use of a modified wing wake to avoid the vertical tail.



**Figure A.2 FROG UAV Model for Obtaining Longitudinal Stability Derivatives.**

## 1. Static Longitudinal Stability Derivatives

### a. Static Longitudinal Stability Equations

Three basic longitudinal stability derivatives can be measured with just two runs of the CMARC model. The model is first analyzed at an angle-of-attack corresponding to the estimated trim condition. For the FROG case,  $\alpha_t=0^\circ$  is selected for the first run based on hand calculations. A second CMARC run is conducted with angle-of-attack incremented by one or two degrees.  $C_L$ ,  $C_D$  and  $C_m$  are then extracted manually from the data files. The slope of  $C_L$ ,  $C_D$  and  $C_m$  versus angle-of-attack provides the  $C_{L\alpha}$ ,  $C_{D\alpha}$  and  $C_{m\alpha}$  longitudinal derivatives. Additional solutions should be obtained to check for lift slope linearity. In addition,  $\alpha_{trim}$  is calculated from the lift curve slope and trim lift coefficient. Equations A.1 through A.4 are used for these calculations.

$$C_{L\alpha} = \frac{(C_{L2} - C_{L1})}{(\alpha_2 - \alpha_1)} * \frac{180}{\pi} \text{ per radian} \quad \text{A.1}$$

$$C_{D\alpha} = \frac{(C_{D2} - C_{D1})}{(\alpha_2 - \alpha_1)} * \frac{180}{\pi} \text{ per radian} \quad \text{A.2}$$

$$C_{m\alpha} = \frac{(C_{m2} - C_{m1})}{(\alpha_2 - \alpha_1)} * \frac{180}{\pi} \text{ per radian} \quad \text{A.3}$$

$$\alpha^\circ_{trim} = \alpha^\circ_1 + \frac{(C_{Ltrim} - C_{L1})}{C_{L\alpha}} * \frac{180}{\pi} \text{ degrees} \quad \text{A.4}$$

### b. Sample Static Longitudinal Stability Data Reduction

Table A.2 presents CMARC solutions for the FROG UAV at two angles-of-attack. Sample calculations for obtaining the static derivatives are demonstrated below. The calculations are easily implemented in a spreadsheet or with a MATLAB script.

RUN #	AOA	CL	CD	CY	C <sub>m</sub>	C <sub>n</sub>	C <sub>l</sub>
1	0°	0.4300	0.0277	0.0000	0.0444	0.0000	0.0000
2	2°	0.5991	0.0370	0.0000	0.0300	0.0000	0.0000

**Table A.2 FROG UAV Static Longitudinal Stability Data.**

**Sample Calculations:**

$$C_{L\alpha} = \frac{(0.5991 - 0.4300)}{(2 - 0)} * \frac{180}{\pi} = 4.8444 \text{ per radian} \quad \text{A.5}$$

$$C_{D\alpha} = \frac{(0.0370 - 0.0277)}{(2 - 0)} * \frac{180}{\pi} = 0.2664 \text{ per radian} \quad \text{A.6}$$

$$C_{m\alpha} = \frac{(0.0300 - 0.0444)}{(2 - 0)} * \frac{180}{\pi} = -0.4125 \text{ per radian} \quad \text{A.7}$$

$$\alpha^{\circ}_{trim} = 0^{\circ} + \frac{(0.4295 - 0.4300)}{4.8444} * \frac{180}{\pi} = -0.0059^{\circ} \approx 0^{\circ} \quad \text{A.8}$$

**c. Sample Total Drag Coefficient Calculation**

The final static longitudinal parameter required is total aircraft drag.  $C_D$  plays an important role in long period aircraft dynamics. Unfortunately, potential flow panel codes such as CMARC do not provide accurate total drag estimates. They can provide good induced drag predictions. In addition, if equipped with a boundary layer code like that contained in CMARC, they can provide integrated skin friction results. However, a large total drag contribution in the form of separation drag is not accounted for. Total drag estimates are made below using the two simple techniques shown in Equations A.9 to A.12. The first method is based on the flight-tested glide ratio. The second is based on cruise power required and estimated prop efficiency. Note that the selected prop efficiency is relatively low due to the FROG UAV small propeller diameter,

high RPM and pusher configuration. The two methods provide drag predictions within 10% of each other. The results are averaged to  $C_D=0.065$ .

Method 1: Lift-to-Drag Ratio ( $L/D=7$  from flight test)

$$L/D = 7 \Rightarrow D = \frac{L}{7} = \frac{W}{7} = \frac{67.7 \text{ lbs}}{7} = 9.67 \text{ lbs} \quad \text{A.9}$$

$$C_D = \frac{D}{qS} = \frac{9.67 \text{ lbs}}{0.5 * 0.002327 \text{ lb} \cdot \text{s}^2 / \text{ft}^4 * 88^2 \text{ ft}^2 / \text{s}^2 * 17.57 \text{ ft}^2} = 0.0611 \quad \text{A.10}$$

Method 2: Cruise Power Setting ( $HP=5$ ,  $\eta_p=0.35$ )

$$C_D = \frac{D}{qS} = \frac{T_R}{qS} = \frac{HP_R * 550 \text{ ft} \cdot \text{lbs} / \text{s} / HP * \eta_p / V}{qS} \quad \text{A.11}$$

$$C_D = \frac{5 \text{ HP} * 550 \text{ ft} \cdot \text{lbs} / \text{s} / \text{HP} * 0.35 / 88 \text{ ft} / \text{s}}{0.5 * 0.002327 \text{ lb} \cdot \text{s}^2 / \text{ft}^4 * 88^2 \text{ ft}^2 / \text{s}^2 * 17.57 \text{ ft}^2} = 0.069 \quad \text{A.12}$$

## 2. Longitudinal Control Power Stability Derivatives

### a. Longitudinal Control Power Equations

The elevator control power derivatives are obtained by substituting a  $0^\circ$  deflection horizontal tail patch for one with positive elevator deflection. Only one run is required. For the FROG UAV study,  $+5^\circ$  (TED) deflection is used. The difference between the trim condition and the deflected value is divided by the elevator deflection as shown below. Note that  $C_{D\delta_e}$  from CMARC only includes induced drag due to elevator deflection:

$$C_{L\delta_e} = \frac{(C_{L\delta_{e2}} - C_{L\delta_{e1}})}{\delta_{e2} - \delta_{e1}} * \frac{180}{\pi} \text{ per rad} \quad \text{A.13}$$

$$C_{D\delta_e} = \frac{(C_{D\delta_{e2}} - C_{D\delta_{e1}})}{\delta_{e2} - \delta_{e1}} * \frac{180}{\pi} \text{ per rad} \quad \text{A.14}$$

$$C_{m\delta_e} = \frac{(C_{m\delta_{e2}} - C_{m\delta_{e1}})}{\delta_{e2} - \delta_{e1}} * \frac{180}{\pi} \text{ per rad} \quad \text{A.15}$$

$$\delta_e^{\circ} \text{ trim} = \frac{(C_{m@trim(\delta_e=0)})}{C_{m\delta_e}} * \frac{180}{\pi} \text{ deg} \quad \text{A.16}$$

**b. Sample Longitudinal Control Power Data Reduction**

Table A.3 presents CMARC solutions for two elevator deflections. Sample calculations for obtaining elevator control power are demonstrated below. The calculations are easily implemented in a spreadsheet or with a MATLAB script.

$$C_{L\delta_e} = \frac{(0.4641 - 0.4259)}{(5 - 0)} * \frac{180}{\pi} = 0.4378 \text{ per radian} \quad \text{A.17}$$

$$C_{D\delta_e} = \frac{(0.0178 - 0.0170)}{(5 - 0)} * \frac{180}{\pi} = 0.0092 \text{ per radian} \quad \text{A.18}$$

$$C_{m\delta_e} = \frac{(-0.0942 - 0.0104)}{(5 - 0)} * \frac{180}{\pi} = -1.199 \text{ per radian} \quad \text{A.19}$$

$$\delta_e^{\circ} \text{ trim} = \frac{(0.0104)}{-1.199} * \frac{180}{\pi} = -0.50^{\circ} \quad \text{A.20}$$

RUN #	$\delta_e$	CL	CD	CY	C m	C n	C l
1	0°	0.4259	0.0170	0.0000	0.0104	0.0000	0.0001
2	5°	0.4641	0.0178	0.0000	-0.0942	0.0000	0.0001

**Table A.3 FROG UAV Elevator Control Power Data.**

### 3. Longitudinal $\alpha$ -dot Damping Derivatives

#### a. Longitudinal $\alpha$ -dot Derivative Methods and Equations

Two motions selected are to develop the longitudinal rate damping derivatives. A sinusoidal plunging motion in the z-axis is used to extract the  $\alpha$ -dot terms. Then an oscillatory pitching motion is used to obtain the combined  $\alpha$ -dot and pitch rate terms. The  $\alpha$ -dot are then subtracted to yield the pitch rate damping. All motion for FROG data gathering is conducted at a frequency of  $2\pi$  rad/s, which equates to a reduced frequency of  $k=0.0595$  for this configuration and trim airspeed.

The sinusoidal plunging motion illustrated in Figure A.3 is used to isolate the  $\alpha$ -dot derivatives. Z-axis plunging motion is controlled with the CMARC BINP8B input file line. A frequency of  $2\pi$  rad/s and an amplitude of  $C/2=10$  inches are selected for the FROG study. Greater amplitude was initially selected, but the induced angle of attack caused the rigid wake to impact the horizontal tail. An example BINP8B input line is shown below:

```
&BINP8B    DXMAX=0.0,      DYMAX=0.0,      DZMAX=10.0  
           WTX=0.0,      WTY=0.0,      WTZ=6.283,      &END
```

The number of time steps and time step interval is chosen to create a nice sinusoidal output through at least two cycles of motion. In the FROG study, a plunging motion frequency of  $\omega=2\pi$  rad/s or one cycle/sec is utilized. Fifty time steps are chosen with an interval of 0.05 seconds, which creates 2.5 cycles of plunging motion. After the solution is obtained, the "total coefficient" data is extracted for plotting. The data can be picked out manually, or a data retrieval program can be created for the task. For the FROG study, the data is extracted manually and pasted into an "Excel" spreadsheet for plotting. In addition to the CMARC output, plunging motion phase angle and induced angle-of-attack are calculated using Equations A.21 and A.22. Induced angle-of-attack is used to find the phase angle of the response with respect to angle-of-attack. Table A.4 shows representative FROG data for 20 time steps.

$$\phi_{plunge} = \#_{timestep} * dt * \omega_{plunge} * \frac{180}{\pi} \text{ degrees} \quad \text{A.21}$$

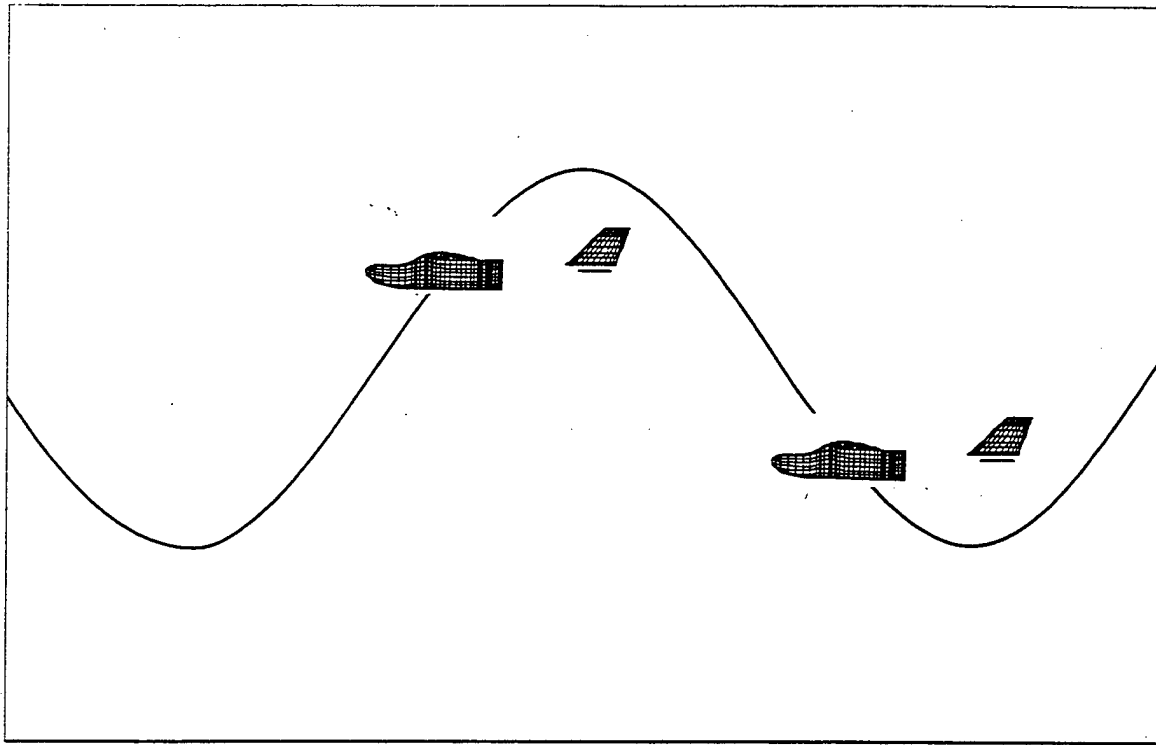
$$\alpha_{induced} = \cos(\phi_{plunge}) \frac{A_{plunge}}{U_o} * \omega_{plunge} * \frac{180}{\pi} \text{ degrees} \quad \text{A.22}$$

Where:

- $\phi_{plunge}$  - plunging motion phase angle
- $\alpha_{induced}$  - induced angle-of-attack from the plunging motion
- $\#_{timestep}$  - time step
- $dt$  - time step interval
- $\omega_{plunge}$  - plunging frequency
- $A_{plunge}$  - plunging amplitude
- $U_o$  - reference free stream velocity

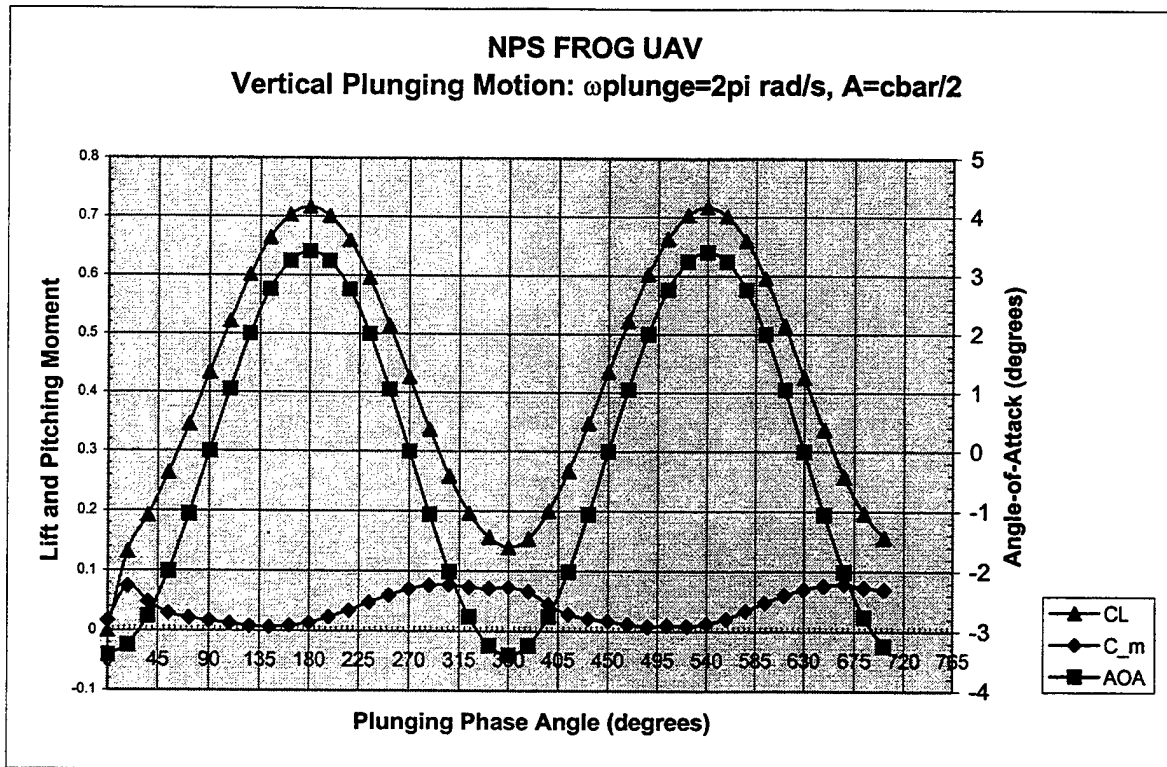
Step	$\phi$ (deg)	$\alpha_{induced}$	CL	CD	CY	C_m	C_n	C_l
0	0	-3.41	0.0001	0.0327	0.0000	0.0173	0.0000	0.0000
1	18	-3.24	0.1318	0.0300	0.0000	0.0744	0.0000	0.0000
2	36	-2.76	0.1928	0.0299	0.0000	0.0485	0.0000	0.0000
3	54	-2.00	0.2631	0.0316	0.0000	0.0294	0.0000	0.0000
4	72	-1.05	0.3451	0.0318	0.0000	0.0218	0.0000	0.0000
5	90	0.00	0.4336	0.0297	0.0000	0.0169	0.0000	0.0000
6	108	1.05	0.5216	0.0252	0.0000	0.0126	0.0000	0.0000
7	126	2.00	0.6009	0.0189	0.0000	0.0087	0.0000	0.0000
8	144	2.76	0.6636	0.0123	0.0000	0.0067	0.0000	0.0000
9	162	3.24	0.7029	0.0069	0.0000	0.0089	0.0000	0.0000
10	180	3.41	0.7160	0.0042	0.0000	0.0139	0.0000	0.0000
11	198	3.24	0.7009	0.0048	0.0000	0.0232	0.0000	0.0000
12	216	2.76	0.6594	0.0085	0.0000	0.0344	0.0000	0.0000
13	234	2.00	0.5952	0.0142	0.0000	0.0474	0.0000	0.0000
14	252	1.05	0.5141	0.0204	0.0000	0.0596	0.0000	0.0000
15	270	0.00	0.4254	0.0255	0.0000	0.0704	0.0000	0.0000
16	288	-1.05	0.3370	0.0286	0.0000	0.0762	0.0000	0.0000
17	306	-2.00	0.2582	0.0297	0.0000	0.0776	0.0000	0.0000
18	324	-2.76	0.1964	0.0292	0.0000	0.0734	0.0000	0.0000
19	342	-3.24	0.1561	0.0283	0.0000	0.0713	0.0000	0.0000
20	360	-3.41	0.1398	0.0277	0.0000	0.0727	0.0000	0.0000

**Table A.4 Sample Plunging Motion Data for 20 Time Steps**

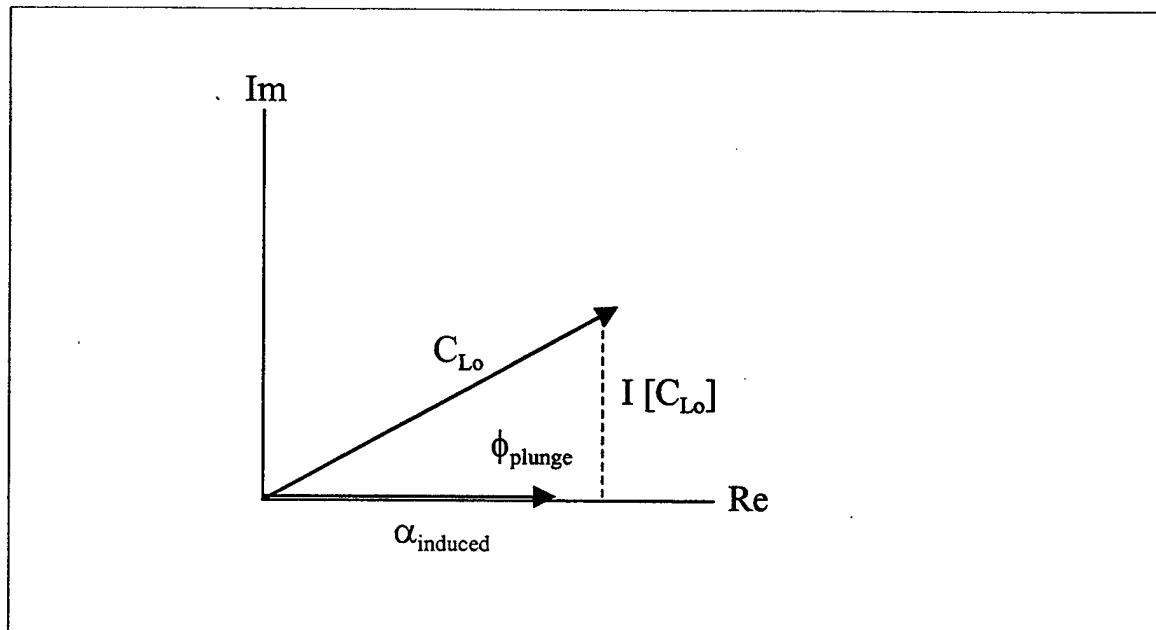


**Figure A.3 Vertical Plunging Motion for Obtaining the  $\alpha$ -dot Derivatives.**

The  $\alpha$ -dot stability derivatives are extracted using the methods outlined in Etkin [Ref. 13]. First, the  $C_L$  and  $C_m$  responses are plotted as a function of plunging phase angle. Induced angle-of-attack is also plotted on the right hand vertical axis. Figure A.4 is a representative plot of CMARC data for the FROG UAV study. The response to plunging motion can be broken up into real and imaginary components. Figure A.5 is a graphical representation of the real and imaginary components. The out-of-phase (imaginary) portion of  $C_L$  or  $C_m$  is the  $\alpha$ -dot contribution. It is normalized by dividing by the amplitude of  $\alpha_{\text{induced}}$  and the reduced frequency. The phase angle is measured between the lift or pitching moment response and the induced angle-of-attack. Equations A.23 through A.27 are used to solve for  $C_{L\dot{\alpha}}$  and  $C_{m\dot{\alpha}}$ .



**Figure A.4 Representative Vertical Plunging Motion Data for the FROG UAV.**



**Figure A.5 Complex Response to Vertical Plunging Motion.**

The phase angle between the  $C_L$  (or  $C_m$ ) response and the induced angle-of-attack is measured graphically or through numerical curve fit techniques. If the graphical method is used, the graph scales may be narrowed around the area of interest to facilitate the phase angle measurement. For instance, Figure A.4 shows that lift coefficient and angle-of-attack are nearly in-phase. When the x-axis scale is zoomed into the peak of the curves, one can see that lift coefficient leads angle-of-attack by one degree. Alternatively, the phase angle may be measured from where the parameter crosses the trim value.

$$C_{L\dot{\alpha}} = \frac{I[C_{L_o}]}{\alpha_o k} \quad \text{A.23}$$

$$C_{m\dot{\alpha}} = \frac{I[C_{m_o}]}{\alpha_o k} \quad \text{A.24}$$

$$\alpha_o = \frac{A}{U_o} \omega_{plunge} \quad \text{A.25}$$

$$I[C_{L_o}] = C_{L_o} \sin(\phi) \quad \text{and} \quad I[C_{m_o}] = C_{m_o} \sin(\phi) \quad \text{A.26}$$

$$k = \frac{\bar{c}/2}{U_o} \omega_{plunge} \quad \text{A.27}$$

- Where:
- $\phi$  - Phase angle between  $C_L$  (or  $C_m$ ) response and  $\alpha_{\text{induced}}$
  - $\alpha_{\text{induced}}$  - Induced angle-of-attack from the plunging motion
  - $C_{L_o}$  - Amplitude of lift coefficient response
  - $C_{m_o}$  - Amplitude of pitching moment coefficient response
  - $\alpha_o$  - Amplitude of the induced angle-of-attack
  - $k$  - Reduced frequency
  - $U_o$  - Reference free stream velocity

**b. Sample Longitudinal  $\alpha$ -dot Data Reduction**

Sample data reduction is presented below in Equations A.28 through A.32. The phase angle between the response and the induced angle-of-attack was measured graphically by zooming the graph axes to expand the area of interest.

$$k = \frac{\bar{c}/2}{U_o} \omega_{plunge} = \frac{20 \text{ in}/2}{1056 \text{ in/s}} * 2\pi \text{ rad/s} = 0.0595 \quad \text{A.28}$$

$$I[C_{L_o}] = C_{L_o} \sin(\phi) = \frac{(0.7160 - 0.1398)}{2} * \sin(1^\circ) = 0.005028 \quad \text{A.29}$$

$$I[C_{m_o}] = C_{m_o} \sin(\phi) = (0.0776 - 0.0087) * \sin(-140^\circ) = -0.0222$$

$$\alpha_o = \frac{A}{U_o} \omega_{plunge} = \frac{20 \text{ in}/2}{1056 \text{ in/s}} * 2\pi = 0.0595 \text{ rad} * \frac{180}{\pi} = 3.41^\circ \quad \text{A.30}$$

$$C_{L\dot{\alpha}} = \frac{I[C_{L_o}]}{\alpha_o k} = \frac{0.005028}{0.0595 * 0.0595} = 1.420 \quad \text{A.31}$$

$$C_{m\dot{\alpha}} = \frac{I[C_{m_o}]}{\alpha_o k} = \frac{-0.0222}{0.0595 * 0.0595} = -6.264 \quad \text{A.32}$$

#### 4. Longitudinal Pitch Rate Damping Derivatives

##### a. Longitudinal Pitch Rate Damping Methods and Equations

A sinusoidal plunging motion in the z-axis was used to extract the  $\alpha$ -dot terms. Now, an oscillatory pitching motion is used to obtain the combined  $\alpha$ -dot and pitch rate terms. The  $\alpha$ -dot influence is then subtracted to yield pitch rate damping. All motion for FROG data gathering is conducted at a frequency of  $2\pi$  rad/s, which equates to a reduced frequency of  $k=0.0595$  for this configuration and trim airspeed.

The sinusoidal pitch rate motion illustrated in Figure A.6 is used to isolate the combined  $\alpha$ -dot and pitch rate influence. Oscillating pitch motion is controlled with the CMARC BINP8A input file line. A frequency of  $2\pi$  rad/s and an amplitude of  $\pm 1.5^\circ$  are selected for the FROG study. Any larger pitch amplitude would cause the wake to impact the horizontal tail. An example BINP8A input line is shown below. Note that pitch amplitude is in degrees and frequency is in rad/sec:

```
&BINP8A  PHIMAX=0.0,    THEMAX=1.5,    PSIMAX=0.0  
          WTX=0.0,      WTY=6.283,    WTZ=0.0,      &END
```

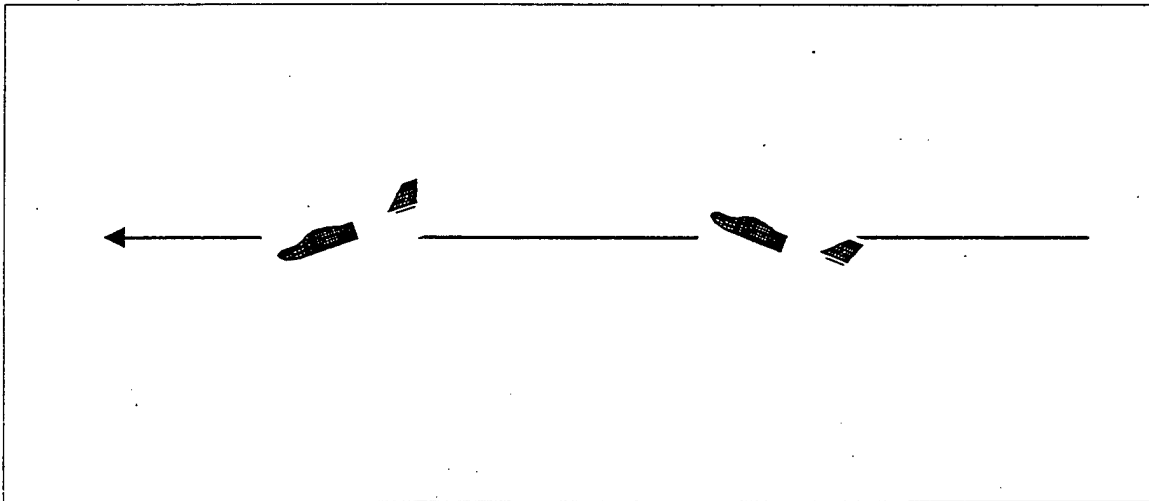


Figure A.6 Pitching Motion for Obtaining the Pitch Rate Damping Derivatives.

The number of time steps and time step interval is chosen to create a nice sinusoidal output through at least two cycles of motion. In the FROG study, a pitching

motion frequency of  $\omega=2\pi$  rad/s or one cycle/sec is utilized. Fifty time steps are chosen with an interval of 0.05 seconds. This combination yields 2.5 cycles of pitching motion. After the solution is obtained, the "total coefficient" data is extracted for plotting. The data can be picked out manually, or a data retrieval program can be created for the task. For the FROG study, the data is extracted manually and pasted into an "Excel" spreadsheet for plotting. In addition to the CMARC output, pitch motion phase angle and angle-of-attack are calculated using Equations A.33 and A.34. Lift and pitching moment phase angle is obtained with respect to angle-of-attack. Usually, the second motion cycle is used to ensure that all start up transients have subsided. Table A.5 shows representative FROG data for 20 time steps.

$$\phi_{pitch} = \#_{timestep} * dt * \omega_{pitch} * \frac{180}{\pi} \text{ degrees} \quad \text{A.33}$$

$$\alpha = \theta = \sin(\phi_{pitch}) A_{pitch} \text{ degrees} \quad \text{A.34}$$

Where:

- $\phi_{pitch}$  - pitching motion phase angle
- $\alpha$  - Angle-of-attack from the pitching motion
- $\#_{timestep}$  - time step
- $dt$  - time step interval
- $\omega_{pitch}$  - pitching frequency
- $A_{pitch}$  - pitch amplitude

Step	$\phi$ (deg)	$\alpha$	CL	CD	CY	C <sub>m</sub>	C <sub>n</sub>	C <sub>l</sub>
0	0	0.00	0.0540	0.0273	0.0000	0.0828	0.0000	0.0000
1	18	0.46	0.4545	0.0364	0.0000	-0.0462	0.0000	0.0000
2	36	0.88	0.4961	0.0344	0.0000	0.0303	0.0000	0.0000
3	54	1.21	0.5312	0.0347	0.0000	0.0226	0.0000	0.0000
4	72	1.43	0.5491	0.0351	0.0000	0.0270	0.0000	0.0000
5	90	1.50	0.5541	0.0348	0.0000	0.0310	0.0000	0.0000
6	108	1.43	0.5435	0.0338	0.0000	0.0447	0.0000	0.0000
7	126	1.21	0.5227	0.0321	0.0000	0.0535	0.0000	0.0000
8	144	0.88	0.4925	0.0302	0.0000	0.0618	0.0000	0.0000
9	162	0.46	0.4557	0.0281	0.0000	0.0692	0.0000	0.0000
10	180	0.00	0.4167	0.0262	0.0000	0.0727	0.0000	0.0000
11	198	-0.46	0.3787	0.0247	0.0000	0.0741	0.0000	0.0000
12	216	-0.88	0.3457	0.0236	0.0000	0.0720	0.0000	0.0000
13	234	-1.21	0.3218	0.0230	0.0000	0.0648	0.0000	0.0000
14	252	-1.43	0.3075	0.0227	0.0000	0.0585	0.0000	0.0000
15	270	-1.50	0.3055	0.0228	0.0000	0.0499	0.0000	0.0000
16	288	-1.43	0.3158	0.0233	0.0000	0.0402	0.0000	0.0000
17	306	-1.21	0.3369	0.0241	0.0000	0.0323	0.0000	0.0000
18	324	-0.88	0.3674	0.0254	0.0000	0.0246	0.0000	0.0000
19	342	-0.46	0.4039	0.0271	0.0000	0.0191	0.0000	0.0000
20	360	0.00	0.4429	0.0290	0.0000	0.0153	0.0000	0.0000

**Table A.5 Sample Pitch Motion Data for 20 Time Steps**

The  $C_L$  and  $C_m$  responses are plotted as a function of pitch motion phase angle. Angle-of-attack is also plotted on the right hand vertical axis. Figure A.7 is a representative plot of CMARC data for the FROG UAV study. The out-of-phase (imaginary) portion of  $C_L$  or  $C_m$  is the combined  $\alpha$ -dot and pitch damping contribution. As seen in Equations A.35 and A.36, the  $\alpha$ -dot contribution is subtracted from the total to yield the pitch damping influence. The pitch rate contribution is normalized by pitch rate and  $t^*$ . The phase angle is measured between the lift or pitching moment response and angle-of-attack. Equations A.35 through A.44 are used to solve for  $C_{Lq}$  and  $C_{mq}$ . Equations A.35 and A.36 assume that the  $\alpha$ -dot and pitch rate contributions are in phase with each other. The  $\alpha$ -dot contribution is small, so there isn't harm done if the two contributions are somewhat out-of-phase. Consequently, the  $\alpha$ -dot contribution is calculated based on the maximum  $\alpha$ -dot rate observed.

$$I[C_{L\dot{\alpha}+q}] = I[C_{L\dot{\alpha}}] + I[C_{Lq}] \quad \text{A.35}$$

$$I[C_{m\dot{\alpha}+q}] = I[C_{m\dot{\alpha}}] + I[C_{mq}] \quad \text{A.36}$$

$$I[C_{L\dot{\alpha}+q}] = \sin(\phi)[C_{L\dot{\alpha}+q}] \quad \text{A.37}$$

$$I[C_{L\dot{\alpha}+q}] = \sin(\phi)[C_{L\dot{\alpha}+q}] \quad \text{A.38}$$

$$I[C_{L\dot{\alpha}}] = C_{L\dot{\alpha}} * \dot{\alpha}_{\max} * t^* \quad \text{A.39}$$

$$I[C_{m\dot{\alpha}}] = C_{m\dot{\alpha}} * \dot{\alpha}_{\max} * t^* \quad \text{A.40}$$

$$I[C_{Lq}] = C_{Lq} * q_{\max} * t^* \quad \text{A.41}$$

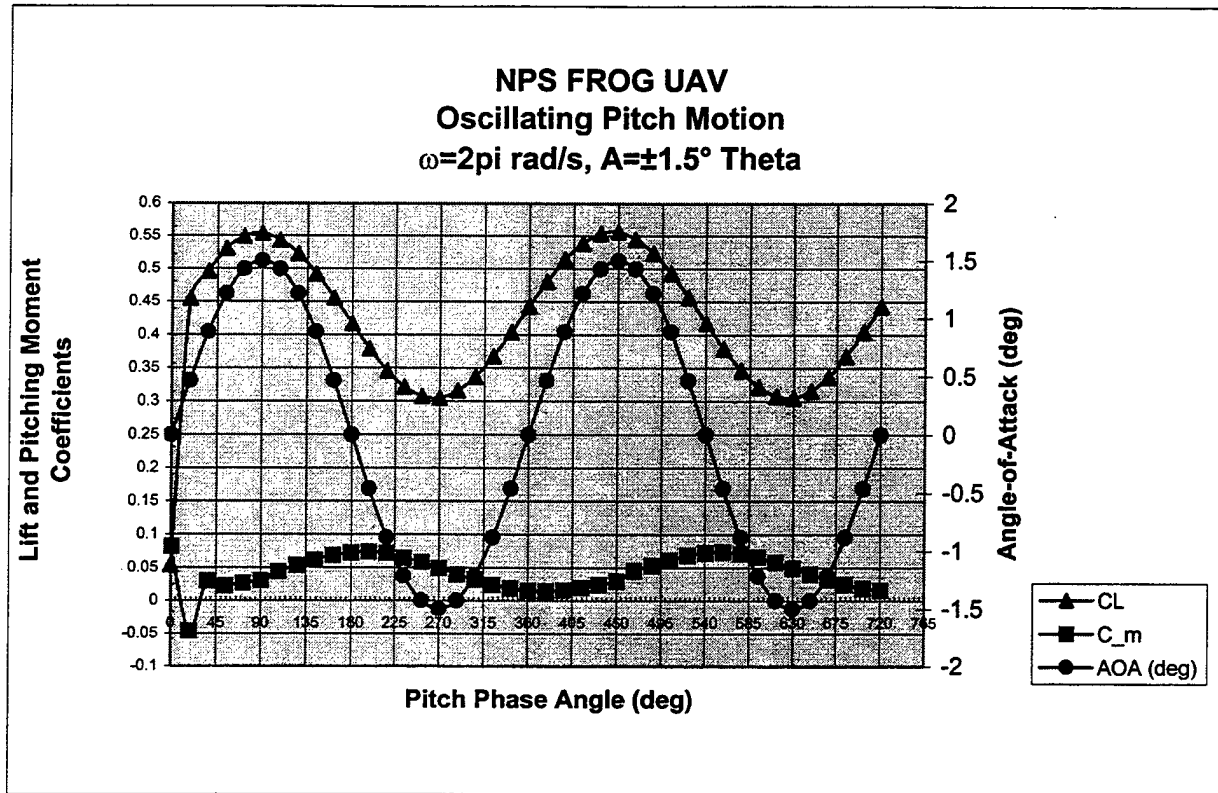
$$I[C_{mq}] = C_{mq} * q_{\max} * t^* \quad \text{A.42}$$

$$q_{\max} = \dot{\alpha}_{\max} = \frac{A_{\theta \text{deg}}}{57.3 \text{deg/rad}} * \omega_{\text{pitch}} \quad \text{rad/s} \quad \text{A.43}$$

$$t^* = \frac{\bar{c}}{2} U_0 \quad \text{A.44}$$

Where:

- $[C_{L \alpha\text{-dot}+q}]$  - Amplitude of  $C_L$  response from pitching motion
- $[C_{m \alpha\text{-dot}+q}]$  - Amplitude of  $C_m$  response from pitching motion
- $I[C_{L \alpha\text{-dot}+q}]$  - Out-of-phase  $C_L$  due to  $\alpha\text{-dot}$  and pitch rate damping
- $I[C_{m \alpha\text{-dot}+q}]$  - Out-of-phase  $C_m$  due to  $\alpha\text{-dot}$  and pitch rate damping
- $I[C_{Lq}]$  -  $C_L$  coefficient contribution from pitch rate damping
- $I[C_{mq}]$  -  $C_m$  coefficient contribution from pitch rate damping
- $I[C_{L \alpha\text{-dot}}]$  -  $C_L$  coefficient contribution from  $\alpha\text{-dot}$  damping
- $I[C_{m \alpha\text{-dot}}]$  -  $C_m$  coefficient contribution from  $\alpha\text{-dot}$  damping
- $t^*$  - Characteristic time



**Figure A.7 Representative Pitch Motion Data for the FROG UAV.**

***b. Sample Pitch Rate Damping Data Reduction***

Sample pitch rate damping data reduction is presented below in Equations A.45 through A.54. The phase angle between angle-of-attack and the  $C_L$  or  $C_m$  response was measured graphically by zooming the graph axes to expand the area of interest.

$$t^* = \frac{\bar{c}/2}{U_0} = \frac{20 \text{ in}}{2} \div 1056 \frac{\text{in}}{\text{sec}} = 0.009470 \text{ sec} \quad \text{A.45}$$

$$q_{\max} = \dot{\alpha}_{\max} = \frac{A_{\theta \text{ deg}}}{57.3 \text{ deg/rad}} * \omega_{\text{pitch}} = \frac{1.5^\circ}{57.3^\circ/\text{rad}} * 2\pi \text{ rad/s} = 0.1645 \text{ rad/s} \quad \text{A.46}$$

$$I[C_{L\dot{\alpha}}] = C_{L\dot{\alpha}} * \dot{\alpha}_{\max} * t^* = 1.420 * 0.1645 * 0.009470 = 0.002212 \quad \text{A.47}$$

$$I[C_{m\dot{\alpha}}] = C_{m\dot{\alpha}} * \dot{\alpha}_{\max} * t^* = -6.264 * 0.1645 * 0.009470 = -0.009758 \quad \text{A.48}$$

$$I[C_{L\dot{\alpha}+q}] = \sin(\phi)[C_{L\dot{\alpha}+q}] = \sin(6^\circ) * [0.1234] = 0.0129 \quad \text{A.49}$$

$$I[C_{m\dot{\alpha}+q}] = \sin(\phi)[C_{m\dot{\alpha}+q}] = \sin(-100^\circ) * [0.02853] = -0.02810 \quad \text{A.50}$$

$$I[C_{Lq}] = I[C_{L\dot{\alpha}+q}] - I[C_{L\dot{\alpha}}] = 0.0129 - 0.002212 = 0.01069 \quad \text{A.51}$$

$$I[C_{mq}] = I[C_{m\dot{\alpha}+q}] - I[C_{m\dot{\alpha}}] = -0.02810 - (-0.009758) = -0.01834 \quad \text{A.52}$$

$$C_{Lq} = \frac{I[C_{Lq}]}{q_{\max} * t^*} = \frac{0.01069}{0.1645 * 0.009470} = 6.862 \quad \text{A.53}$$

$$C_{mq} = \frac{I[C_{mq}]}{q_{\max} * t^*} = \frac{-0.01834}{0.1645 * 0.009470} = -11.78 \quad \text{A.54}$$

### C. LATERAL-DIRECTIONAL STABILITY DERIVATIVES

This section will describe CMARC methods for the development of lateral-directional stability derivatives to include the static, rate damping and control power derivatives. The results obtained from CMARC should be spot checked against classical design calculations.

Of note, CMARC uses the semi-span to normalize rolling and yawing moment coefficients. Most texts on stability and control, including Roskam [Ref. 12] and Etkin [Ref. 13], normalize rolling and yawing moments by span. This study will normalize roll and yaw moments by span. Table A.1 summarizes the factors for normalizing moments and angular rates. All rolling and yawing moment coefficients presented in this study have been normalized with span by dividing the CMARC output by a factor of two. Table A.1 also indicates the characteristic time,  $t^*$ , employed for angle rate data reduction.

For the lateral-directional analysis, both sides of the body must be modeled. The easiest way to do this is to activate the symmetric patch toggle for each patch (IPATSYM=1). Then, turn off symmetric calculations (RSYM=1.0). This creates symmetric patches around the  $y=0$  plane, allowing CMARC to perform asymmetric calculations around the entire body. Processing times are significantly increased compared to the symmetric case. Wakes must be defined for each side of the model based on the new patch numbers. In addition, don't forget to update the adjacent patch numbers of the wingtips.

The vertical tail is activated for the lateral-directional study. This requires that the wing and fuselage group be run separately from the horizontal and vertical stabilizer group. This de-coupling is required to keep the wing wake from hitting the vertical stabilizer. The two sets of results are summed to get the total response. Typically, the sidewash derivative,  $d\epsilon/d\beta$  is small, making separate solutions feasible. The main drawback is that separate solutions will not capture the finer interactions that a complete model would capture. However, many aircraft configurations will not require the de-coupling of the empennage surfaces. If the configuration permits, run the lateral-directional test cases as a complete airframe model. Figure A.8 shows the FROG model configurations used to find the lateral-directional derivatives.

It should be noted that the CMARC wind axes are modeled with X-aft/Z-up, vice X-forward/Z-down for the typical stability axes system. Positive yaw angle in CMARC creates positive sideslip in the stability axes system. Care must be taken to reverse the signs of the appropriate coefficients to convert from the CMARC wind axes to the stability axis system shown in Figure A.1.

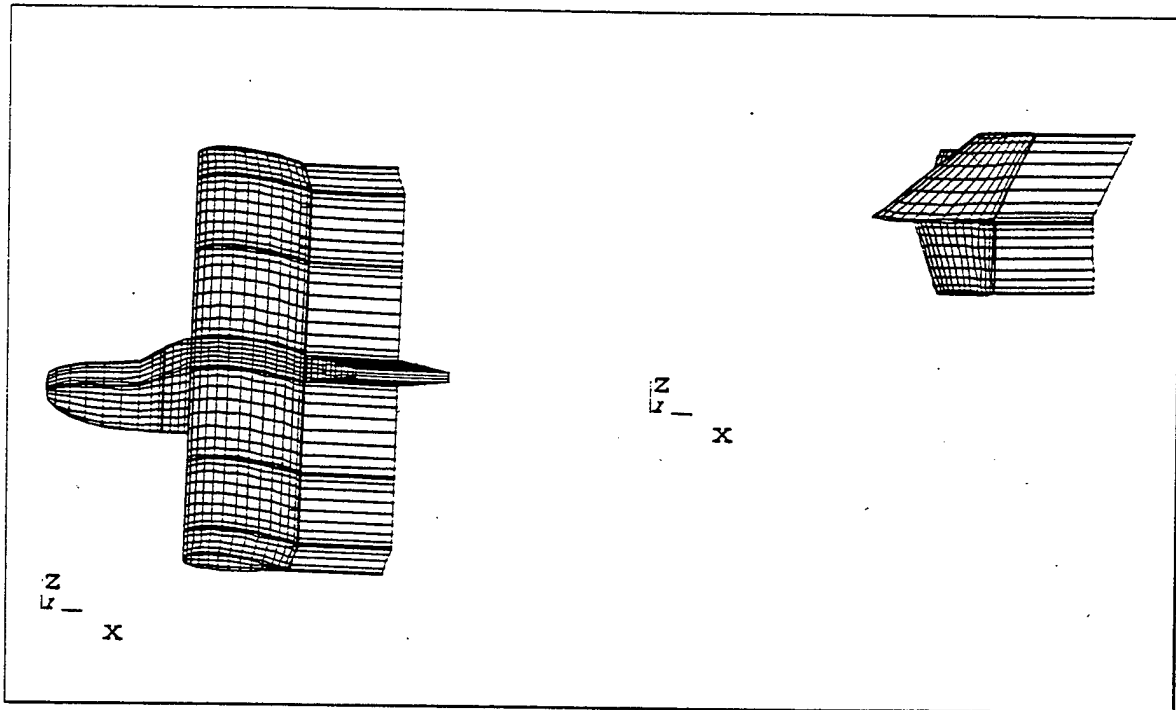


Figure A.7 FROG UAV Lateral-Directional Models.

## 1. Static Lateral Directional Stability Derivatives

### a. *Static Lateral-Directional Stability Equations*

Three lateral-directional stability derivatives are measured with the first two runs of the CMARC model. The model is first analyzed at the estimated trim condition with zero sideslip. The baseline solution should be compared to the longitudinal baseline. If the lift coefficient differs significantly, the wake modification assumptions may need to be revisited. The model is then checked for lateral-directional

balance at zero sideslip angle (yaw angle =0). The side force, rolling and yawing coefficients should be zero when a trial run is performed at zero sideslip. If lateral-directional forces or moments are present, the model and wake geometry should be checked for symmetry. Visualization with LOFTSMAN will assist in spotting the problem.

For the FROG case,  $\alpha_{trim}=0^\circ$  and  $\beta=0^\circ$  is selected for the baseline. A second CMARC run is then conducted with yaw angle incremented by one or two degrees.  $C_Y$ ,  $C_l$  and  $C_n$  are then extracted manually from the data files. The slope of  $C_Y$ ,  $C_l$  and  $C_n$  versus sideslip provides the  $C_{Y\beta}$ ,  $C_{l\beta}$  and  $C_{n\beta}$  longitudinal derivatives. Additional solutions can be obtained to check for slope linearity. Equations A.55 through A.57 are used for these calculations:

$$C_{Y\beta} = \frac{C_Y}{\Delta\beta^\circ} * \frac{180}{\pi} \text{ per radian} \quad \text{A.55}$$

$$C_{l\beta} = \frac{C_l}{\Delta\beta^\circ} * \frac{180}{\pi} \text{ per radian} \quad \text{A.56}$$

$$C_{n\beta} = \frac{C_n}{\Delta\beta^\circ} * \frac{180}{\pi} \text{ per radian} \quad \text{A.57}$$

#### ***b. Sample Static Lateral-Directional Data Reduction***

Table A.6 presents CMARC solutions for the FROG UAV at two angles-of-attack. Data is for the summed contribution of the wing/fuselage and tail group models. Roll and yaw moments are already divided by a factor of two. This normalizes by span to compensate for the CMARC output, which is normalized by semi-span. Sample calculations for obtaining the static derivatives are demonstrated below. The calculations are easily implemented in a spreadsheet or with a MATLAB script.

RUN #	$\beta$	CL	CD	CY	C <sub>m</sub>	C <sub>n</sub>	C <sub>l</sub>
1	0°	0.4432	0.0145	0.0000	0.0048	0.0000	0.0000
2	2°	0.4452	0.0148	-0.0087	0.0038	0.0022	-0.0022

**Table A.6 FROG UAV Static Lateral-Directional Stability Data at  $\alpha_{trim}=0^\circ$ .**

### Sample Calculations:

$$C_{Y\beta} = \frac{C_Y}{\Delta\beta^\circ} * \frac{180}{\pi} = \frac{-0.0087}{2^\circ} * \frac{180 \text{ deg}}{\pi \text{ rad}} = -0.2493 \text{ per radian} \quad \text{A.55}$$

$$C_{l\beta} = \frac{C_l}{\Delta\beta^\circ} * \frac{180}{\pi} = \frac{-0.0022}{2^\circ} * \frac{180 \text{ deg}}{\pi \text{ rad}} = 0.0630 \text{ per radian} \quad \text{A.56}$$

$$C_{n\beta} = \frac{C_n}{\Delta\beta^\circ} * \frac{180}{\pi} = \frac{0.0022}{2^\circ} * \frac{180 \text{ deg}}{\pi \text{ rad}} = 0.0630 \text{ per radian} \quad \text{A.57}$$

### 3. Lateral-Directional Control Power Stability Derivatives

#### a. Lateral-Directional Control Power Equations

The rudder control power derivatives are obtained by substituting a 0° deflection vertical stabilizer patch for one with positive rudder deflection. Only one run is required. For the FROG UAV study, +5° (TEL) deflection is used. The difference between the trim condition and the deflected value is divided by the rudder deflection as shown below:

$$C_{Y\delta a} = \frac{(C_{Y\delta a_2} - C_{Y\delta a_1})}{\delta a_2 - \delta a_1} * \frac{180}{\pi} \text{ per rad} \quad \text{A.58}$$

$$C_{l\delta a} = \frac{(C_{l\delta a_2} - C_{l\delta a_1})}{\delta a_2 - \delta a_1} * \frac{180}{\pi} \text{ per rad} \quad \text{A.59}$$

$$C_{n\delta a} = \frac{(C_{n\delta a_2} - C_{n\delta a_1})}{\delta a_2 - \delta a_1} * \frac{180}{\pi} \text{ per rad} \quad \text{A.60}$$

$$C_{Y\delta r} = \frac{(C_{Y\delta r_2} - C_{Y\delta r_1})}{\delta r_2 - \delta r_1} * \frac{180}{\pi} \text{ per rad} \quad \text{A.61}$$

$$C_{l\delta r} = \frac{(C_{l\delta r_2} - C_{l\delta r_1})}{\delta r_2 - \delta r_1} * \frac{180}{\pi} \text{ per rad} \quad \text{A.62}$$

$$C_{n\delta r} = \frac{(C_{n\delta r_2} - C_{n\delta r_1})}{\delta r_2 - \delta r_1} * \frac{180}{\pi} \text{ per rad} \quad \text{A.63}$$

**b. Sample Lateral-Directional Control Power Data Reduction**

Tables A.7 and A.8 present CMARC solutions for aileron and rudder deflections. Sample calculations for obtaining aileron and rudder control power are demonstrated below. The calculations are easily implemented in a spreadsheet or with a MATLAB script.

$$C_{Y\delta a} = \frac{(C_{Y\delta a_2} - C_{Y\delta a_1})}{\delta a_2 - \delta a_1} * \frac{180}{\pi} = \frac{(-0.0018 - 0)}{(5 - 0)} * \frac{180}{\pi} = -0.0103 \quad \text{A.64}$$

$$C_{l\delta a} = \frac{(C_{l\delta a_2} - C_{l\delta a_1})}{\delta a_2 - \delta a_1} * \frac{180}{\pi} = \frac{(0.01695 - 0)}{(5 - 0)} * \frac{180}{\pi} = 0.1943 \quad \text{A.65}$$

$$C_{n\delta a} = \frac{(C_{n\delta a_2} - C_{n\delta a_1})}{\delta a_2 - \delta a_1} * \frac{180}{\pi} = \frac{(-0.00105 - 0)}{(5 - 0)} * \frac{180}{\pi} = -0.0120 \quad \text{A.66}$$

$$C_{Y\delta r} = \frac{(C_{Y\delta r_2} - C_{Y\delta r_1})}{\delta r_2 - \delta r_1} * \frac{180}{\pi} = \frac{(0.0081 - 0)}{(5 - 0)} * \frac{180}{\pi} = 0.0928 \quad \text{A.67}$$

$$C_{l\delta r} = \frac{(C_{l\delta r_2} - C_{l\delta r_1})}{\delta r_2 - \delta r_1} * \frac{180}{\pi} = \frac{(0.00035 - 0)}{(5 - 0)} * \frac{180}{\pi} = 0.0040 \quad \text{A.68}$$

$$C_{n\delta r} = \frac{(C_{n\delta r_2} - C_{n\delta r_1})}{\delta r_2 - \delta r_1} * \frac{180}{\pi} = \frac{(-0.00395 - 0)}{(5 - 0)} * \frac{180}{\pi} = -0.0453 \quad \text{A.69}$$

RUN #	$\delta a$	CL	CD	CY	C <sub>m</sub>	C <sub>n</sub>	C <sub>l</sub>
1	0°	0.4259	0.0170	0.0000	0.0104	0.0000	0.0000
2	5°	0.4005	0.0173	-0.0018	0.0199	-0.00105	0.01695

**Table A.7 FROG UAV Aileron Control Power Data at  $\alpha_{trim}=0^\circ$ .**

RUN #	$\delta r$	CL	CD	CY	C <sub>m</sub>	C <sub>n</sub>	C <sub>l</sub>
1	0°	0.4259	0.0170	0.0000	0.0104	0.0000	0.0000
2	5°	0.4258	0.0170	0.0081	0.0107	-0.00395	0.00035

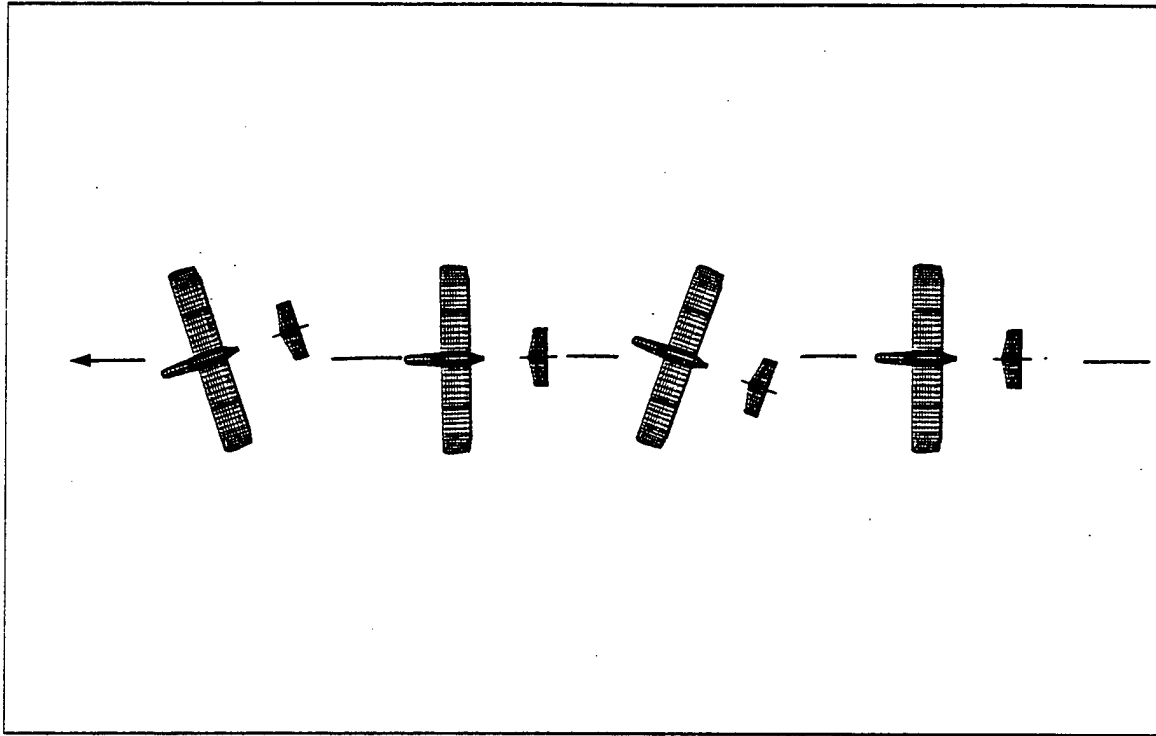
**Table A.8 FROG UAV Rudder Control Power Data at  $\alpha_{trim}=0^\circ$ .**

### 3. Yaw Rate Damping Derivatives

#### *a. Yaw Rate Derivative Methods and Equations*

Only one motion is required for the yaw rate terms. The  $\beta$ -dot terms are generally considered negligible. Therefore, a sideways plunging motion is not required. The yaw rate terms are yielded directly from an oscillating yawing motion as depicted in Figure A.8. Yawing motion data for the FROG is gathered at a frequency of  $2\pi$  rad/s, which equates to a reduced frequency of  $k=0.369$  for this configuration and trim airspeed. Oscillating yaw motion is controlled with the CMARC BINP8A input file line. An amplitude of  $\pm 2^\circ$  is selected for the FROG study. An example BINP8A input line is shown below. Note that yaw amplitude is in degrees and frequency is in rad/sec:

```
&BINP8A  PHIMAX=0.0,      THEMAX=1.5,      PSIMAX=0.0
          WTX=0.0,        WTY=6.283,      WTZ=0.0,      &END
```



**Figure A.8 Yawing Motion for Obtaining the Yaw Rate Derivatives.**

The number of time steps and time step interval is chosen to create a nice sinusoidal output through at least two cycles of motion. In the FROG study, a yawing motion frequency of  $\omega=2\pi$  rad/s or one cycle/sec is utilized. Fifty time steps are chosen with an interval of 0.05 seconds, which creates 2.5 cycles of yawing motion. After the solution is obtained, the "total coefficient" data is extracted for plotting. The data can be picked out manually, or a data retrieval program can be created for the task. For the FROG study, the data is extracted manually and pasted into an "Excel" spreadsheet for plotting. As discussed earlier, the FROG model was split into wing/fuselage and tail groups for the lateral-directional study. Both sets of data are pasted into the Excel spreadsheet and summed. The total value is then plotted. In addition, yawing motion phase and sideslip angles are also calculated using Equations A.70 and A.71. Yawing motion phase angle is plotted on the x-axis and sideslip is plotted on the right hand axis. Table A.9 shows representative FROG yaw rate data for 20 time steps.

$$\phi_{yaw} = \#_{timestep} * dt * \omega_{yaw} * \frac{180}{\pi} \text{ degrees} \quad \text{A.70}$$

$$\beta = \sin(\phi_{yaw}) * A_{yaw} \text{ degrees}$$

A.71

Where:

- $\phi_{yaw}$  - yawing motion phase angle
- $\beta$  - Sideslip angle from yawing motion
- $\#_{timestep}$  - time step
- $dt$  - time step interval
- $\omega_{yaw}$  - Yawing frequency
- $A_{yaw}$  - Yaw angle amplitude

Step	$\phi$ (deg)	$\beta$	CL	CD	CY	C_m	C_n	C_l
0	0	0.00	0.0534	0.0111	-0.0005	0.085	0.0003	-0.0002
1	18	0.62	0.4004	0.0195	-0.007	-0.0107	0.0023	-0.0023
2	36	1.18	0.4329	0.0161	-0.0087	-0.0009	0.0026	-0.0026
3	54	1.62	0.4388	0.0152	-0.0098	0.0019	0.0027	-0.0027
4	72	1.90	0.4416	0.0149	-0.0098	0.0027	0.0026	-0.0026
5	90	2.00	0.4428	0.0149	-0.0089	0.0033	0.0022	-0.0022
6	108	1.90	0.4435	0.0147	-0.0071	0.0039	0.0016	-0.0016
7	126	1.62	0.444	0.0146	-0.0046	0.0044	0.0008	-0.0008
8	144	1.18	0.4444	0.0146	-0.0017	0.0049	0.0000	0.0000
9	162	0.62	0.4447	0.0144	0.0014	0.0051	-0.0009	0.0009
10	180	0.00	0.445	0.0144	0.0043	0.0048	-0.0016	0.0016
11	198	-0.62	0.4452	0.0145	0.0069	0.0044	-0.0022	0.0022
12	216	-1.18	0.4453	0.0146	0.0087	0.004	-0.0026	0.0026
13	234	-1.62	0.4452	0.0147	0.0098	0.0035	-0.0027	0.0027
14	252	-1.90	0.4451	0.0147	0.0098	0.0034	-0.0026	0.0025
15	270	-2.00	0.4449	0.0148	0.0089	0.0036	-0.0022	0.0021
16	288	-1.90	0.4448	0.0146	0.0071	0.0041	-0.0016	0.0015
17	306	-1.62	0.4449	0.0146	0.0046	0.0045	-0.0008	0.0008
18	324	-1.17	0.445	0.0145	0.0017	0.005	0.0000	-0.0001
19	342	-0.62	0.4452	0.0144	-0.0014	0.0051	0.0009	-0.0009
20	360	0.00	0.4454	0.0144	-0.0044	0.0049	0.0016	-0.0016

**Table A.9 Sample FROG UAV Yawing Motion Data for 20 Time Steps**

The  $C_y$ ,  $C_l$  and  $C_m$  responses are plotted as a function of yawing phase angle. Sideslip is also plotted on the right hand vertical axis. Figure A.9 is a representative plot of CMARC data for the FROG UAV study. The out-of-phase (imaginary) portion of  $C_y$ ,  $C_l$  or  $C_m$  is due to the yaw rate damping contribution. The  $\beta$ -dot contribution is considered small and is ignored. The phase angle is measured between the coefficient response and sideslip angle. In this case, the zero crossing

method of measuring phase angle proves to be the easiest and most accurate. The phase angle is simply measured from the parameter to sideslip angle where they cross the x-axis in the same direction. The yaw rate damping contribution is normalized by maximum yaw rate and  $t^*$ . Equations A.72 through A.76 are used to solve for  $C_{Yr}$ ,  $C_{lr}$  and  $C_{nr}$ .

$$C_{Yr} = \frac{I[C_Y]}{r_{\max} * t^*}, \text{ where } I[C_Y] = \sin(\phi_{yaw}) [C_Y] \quad \text{A.72}$$

$$C_{lr} = \frac{I[C_l]}{r_{\max} * t^*}, \text{ where } I[C_l] = \sin(\phi_{yaw}) [C_l] \quad \text{A.73}$$

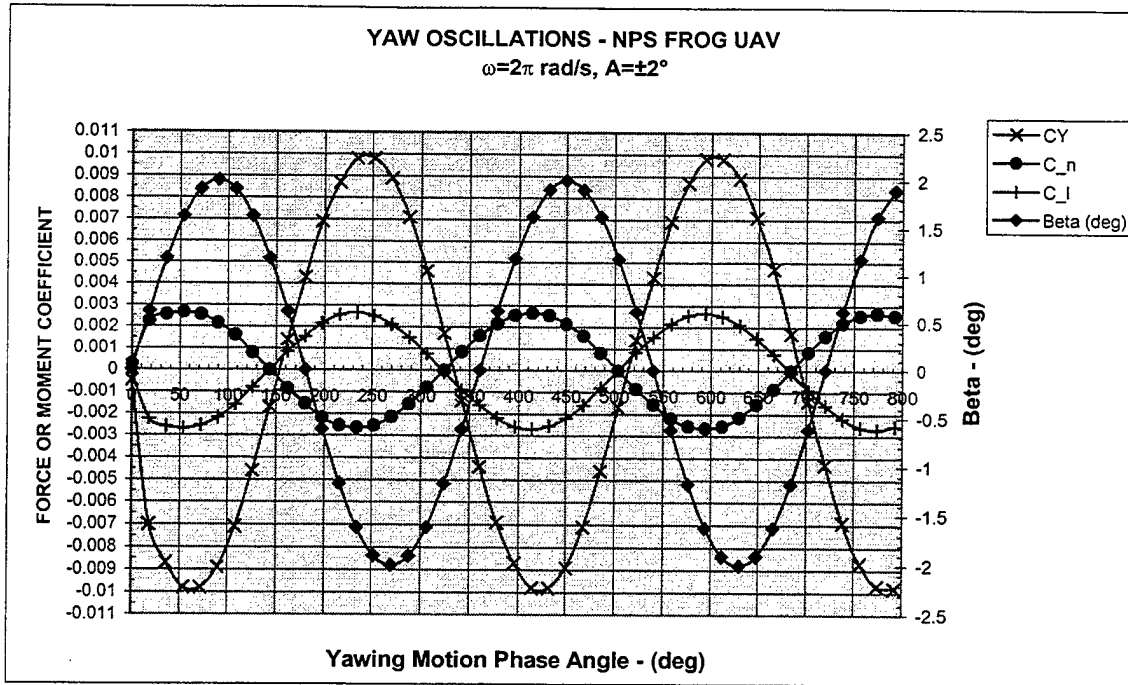
$$C_{nr} = \frac{I[C_n]}{r_{\max} * t^*}, \text{ where } I[C_n] = \sin(\phi_{yaw}) [C_n] \quad \text{A.74}$$

$$r_{\max} = \frac{A_{\phi \text{ deg}}}{57.3 \frac{\text{deg}}{\text{rad}}} * \omega_{yaw} \text{ rad/s} \quad \text{A.75}$$

$$t^* = \frac{b/2}{U_0} \text{ sec} \quad \text{A.76}$$

Where:

$[C_Y]$	- Amplitude of $C_Y$ response from yawing motion
$[C_l]$	- Amplitude of $C_l$ response from yawing motion
$[C_n]$	- Amplitude of $C_n$ response from yawing motion
$I[C_Y]$	- $C_Y$ coefficient contribution from yaw rate damping
$I[C_l]$	- $C_l$ coefficient contribution from yaw rate damping
$I[C_n]$	- $C_n$ coefficient contribution from yaw rate damping
$t^*$	- Characteristic time



**Figure A.9 Representative Yawing Motion Plot for the FROG UAV.**

**b. Sample Yaw Rate Damping Data Reduction**

Sample data reduction is presented below in Equations A.28 through A.32. The phase angle between the response and the sideslip angle is measured graphically by zooming in on the x-axis zero crossing.

$$t^* = \frac{b/2}{U_0} = \frac{124 \text{ in}/2}{1056 \text{ in/s}} = 0.0587 \text{ sec} \quad \text{A.77}$$

$$r_{\max} = \frac{A_{\phi \text{ deg}}}{57.3^\circ/\text{rad}} * \omega_{\text{yaw}} = \frac{2^\circ}{57.3^\circ/\text{rad}} * 2\pi \text{ rad/sec} = 0.2193 \text{ rad/s} \quad \text{A.78}$$

$$C_{Y_r} = \frac{I[C_Y]}{r_{\max} * t^*} = \frac{\sin(\phi_{yaw})[C_Y]}{r_{\max} * t^*} = \frac{\sin(154^\circ)[0.0099]}{0.2193 * 0.0587} = 0.3371 \quad \text{A.79}$$

$$C_{l_r} = \frac{I[C_l]}{r_{\max} * t^*} = \frac{\sin(\phi_{yaw})[C_l]}{r_{\max} * t^*} = \frac{\sin(144^\circ)[0.00265]}{0.2193 * 0.0587} = 0.1210 \quad \text{A.80}$$

$$C_{n_r} = \frac{I[C_n]}{r_{\max} * t^*} = \frac{\sin(\phi_{yaw})[C_n]}{r_{\max} * t^*} = \frac{\sin(-36^\circ)[0.00265]}{0.2193 * 0.0587} = -0.1210 \quad \text{A.81}$$

#### 4. Roll Rate Damping Derivatives

##### a. Roll Rate Derivative Methods and Equations

Gathering roll damping data is straightforward. Unlike the pitch or yaw rate terms, there is no change in angle-of-attack or sideslip with the rolling motion. Therefore, roll damping effects can be measured with pure rolling motion around the x-axis. As with the yaw damping case, the wing/fuselage and tail models are run separately. The results are then summed. A rigid wake seems to work well, which provides a solution after just a few time steps.

Roll damping data for the FROG is gathered at a 20 deg/sec roll rate. Initially, a 5 deg/sec roll rate was selected, but the yawing moment coefficient was low enough that numerical resolution would effect the results. The higher rate provided a sufficiently large response for all terms. Pure rolling motion is controlled by the PHIDOT term in the CMARC BINP8 input file line. An example BINP8 input line is shown below. Note that roll rate is in deg/sec:

```
&BINP8      ALDEG=0.0,      YAWDEG=0.0,      PHIDOT=20.0
            THEDOT=0.0,      PSIDOT=0.0,      &END
```

The roll rate damping terms are obtained by normalizing the CMARC output by roll rate, p, and characteristic time, t\*. Equations A.82 through A.85 are used for these calculations.

$$C_{Yp} = \frac{C_Y}{p^* t^*} \quad \text{A.82}$$

$$C_{lp} = \frac{C_l}{p^* t^*} \quad \text{A.83}$$

$$C_{np} = \frac{C_n}{p^* t^*} \quad \text{A.84}$$

$$t^* = \frac{b/2}{U_0} \text{ sec} \quad \text{A.85}$$

Where:

- |         |  |
|---------|--|
| $[C_Y]$ | - Amplitude of $C_Y$ response from roll rate |
| $[C_l]$ | - Amplitude of $C_l$ response from roll rate |
| $[C_n]$ | - Amplitude of $C_n$ response from roll rate |
| $p$     | - Roll rate                                  |
| $t^*$   | - Characteristic time                        |

**d. Sample Roll Rate Damping Data Reduction**

Tables A.10 presents the CMARC roll damping solution for the FROG UAV. The data is the summed contributions from the wing/fuselage and tail surface models. Sample roll damping calculations presented below in Equations A.86 through A.89. The calculations are easily implemented in a spreadsheet or with a MATLAB script.

$$t^* = \frac{b/2}{U_0} = \frac{62in}{1056in/s} = 0.0587 \text{ sec} \quad \text{A.86}$$

$$C_{Yp} = \frac{C_Y}{p * t^*} = \frac{0.0010}{20 \frac{\text{deg}}{\text{sec}} * \frac{\pi}{180} \frac{\text{deg}}{\text{rad}} * 0.0587 \text{ sec}} = 0.0488 \quad \text{A.87}$$

$$C_{lp} = \frac{C_l}{p * t^*} = \frac{-0.00925}{20 \frac{\text{deg}}{\text{sec}} * \frac{\pi}{180} \frac{\text{deg}}{\text{rad}} * 0.0587 \text{ sec}} = 0.4514 \quad \text{A.88}$$

$$C_{np} = \frac{C_n}{p * t^*} = \frac{-0.00045}{20 \frac{\text{deg}}{\text{sec}} * \frac{\pi}{180} \frac{\text{deg}}{\text{rad}} * 0.0587 \text{ sec}} = -0.0220 \quad \text{A.89}$$

RUN #	p	CL	CD	CY	C <sub>m</sub>	C <sub>n</sub>	C <sub>l</sub>
1	0 deg/s	0.4432	0.0145	0.0000	0.0048	0.0000	0.0000
2	20 deg/s	0.4435	0.0143	0.0010	0.0047	-0.00045	-0.00925

**Table A.10 FROG UAV Roll Damping Data at  $\alpha_{\text{trim}}=0^\circ$  and  $\beta=0^\circ$ .**



**APPENDIX B**

**LOFTSMAN INPUT FILES FOR FROG UAV MODELING**



# FROG UAV Fuselage Moldlines

File name: fogfusa  
Last revision: 4/12/97

## BOTTOM WATERLINE

Segments: 3

Fore end 0,6.5  
Aft end 12,0 53,0,0 53,5,5,75  
Corner 0,0 S 53,5,0  
Curvature .69 0.95

## WAIST WATERLINE

Segments: 1

Fore end 0,6.5  
Aft end 53,5,6.5  
Corner S  
Curvature

## TOP WATERLINE

Segments: 7

Fore end 0,6.5  
Aft end 8,9.3 15,2,9.3 21,6,13,0 29,0,14,6 44,6,11,6  
53,0,11,5 53,5,6.5  
Corner 0,9.3 S 24,3,14,6 35,4,14,6  
S 53,5,11,5  
Curvature 0.7 0.71 0.81  
.95

## MAXIMUM BUTTLIN DISTANCE FROM PLANE OF SYMMETRY

Segments: 6

Fore end 0,0  
Aft end 1,3 1,3 22,4,5 43,6,4,5 53,1,1,3 53,5,0  
Corner 0,2,9 S S S  
53,5,1,3  
Curvature .9 0.8 0.95

## BOTTOM K FACTOR

Segments: 3

Fore end 0,0,0.93  
Aft end 12,0,0.98 43,6,0,98 53,5,0,95  
Corner S  
Curvature

## TOP K FACTOR

Segments: 4

Fore end 0,0,0.90  
Aft end 15,20,0,95 24,1,0 44,65,1,0 53,5,0,95  
Corner S S S  
Curvature

## BUTTLIN AT PLANE OF SYMMETRY

Segments: 0

NPS FROG UAV Right Wing - Loftsmen Input File

Date: 3/30/98

Breaks: 5

Break 1

Axis: 24.65,0,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 2

Axis: 24.65,6,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 3

Axis: 24.65,31.5,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 4

Axis: 24.65,53.0,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 5

Axis: 24.65,61.0,13.1

Axis/chord: 0

Chord: 18.5

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

NPS FROG UAV Left Wing - Loftsmen Input File

Date: 3/30/98

Breaks: 5

Break 1

Axis: 24.65,0,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 2

Axis: 24.65,-6,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 3

Axis: 24.65,-31.5,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 4

Axis: 24.65,-53.0,13.1

Axis/chord: 0

Chord: 20.0

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 5

Axis: 24.65,-61.0,13.1

Axis/chord: 0

Chord: 18.5

Incidence: 4.5

Cant: 0

Section file: N2415

T/C ratio: 0.1500

Spars: 0

FROG Horizontal Tail

Date: 4/14/97

Breaks: 2

Break 1

Axis: 82.5,0,8.09

Axis/chord: 0

Chord: 13.5

Incidence: 0

Cant: 0

Section file: N0006

T/C ratio: 0.06

Spars: 0

Panel rib angles: 0,999.0000,0.0000

Break 2

Axis: 86.5,19.875,8.09

Axis/chord: 0

Chord: 9.55

Incidence: 0

Cant: 0

Section file: N0006

T/C ratio: 0.06

Spars: 0

Panel rib angles: 0,999.0000,0.0000

FROG UAV Vertical Tail - LOFTSMAN input file

Date: 4/14/97

Breaks: 2

Break 1

Axis: 77.5,0,10.4

Axis/chord: 0

Chord: 20

Incidence: 0

Cant: 90

Section file: N0006

T/C ratio: 0.06

Spars: 0

Panel rib angles: 90,0,999

Break 2

Axis: 92.35,0,25.15

Axis/chord: 0

Chord: 10

Incidence: 0

Cant: 90

Section file: N0006

T/C ratio: 0.06

Spars: 0

Panel rib angles: 90,0,999

FROG UAV Vertical Tail - LOFTSMAN input file

Date: 4/14/97 Mod; 8/5/98 to include projected area of vstab through tail boom.

Breaks: 2

Break 1

Axis: 75.6,0,8.5

Axis/chord: 0

Chord: 20

Incidence: 0

Cant: 90

Section file: N0006

T/C ratio: 0.06

Spars: 0

Panel rib angles: 90,0,999

Break 2

Axis: 92.35,0,25.15

Axis/chord: 0

Chord: 10

Incidence: 0

Cant: 90

Section file: N0006

T/C ratio: 0.06

Spars: 0

Panel rib angles: 90,0,999

FROG UAV Tail Boom

File name: frogboom

Last revision: 4/28/97

4/28: added rounded start and finish to close ends

BOTTOM WATERLINE

Segments: 3

Fore end	53.5,9.375	
Aft end	54,8.5	88,8.5
88.5,9.375		
Corner	53.5,8.5	S
88.5,8.5		
Curvature	0.707	
0.707		

WAIST WATERLINE

Segments: 1

Fore end	53.5,9.375
Aft end	88.5, 9.375
Corner	S
Curvature	

TOP WATERLINE

Segments: 3

Fore end	53.5,9.375	
Aft end	54.0,10.25	88,10.25
88.5,9.375		
Corner	53.5,10.25	S
88.5,10.25		
Curvature	0.707	
0.707		

MAXIMUM BUTTLINE DISTANCE FROM PLANE OF SYMMETRY

Segments: 3

Fore end	53.5,0	
Aft end	54,0.875	88,0.875
88.5,0		
Corner	53.5,0.875	S
88.5,0.875		
Curvature	0.707	
0.707		

BOTTOM K FACTOR

Segments: 1

Fore end	53.5,0.707
Aft end	88.5, 0.707
Corner	S
Curvature	

TOP K FACTOR

Segments: 1

Fore end	53.5,0.707
Aft end	88.5, 0.707
Corner	S
Curvature	

BUTTLINE AT PLANE OF SYMMETRY

Segments: 0

FROG UAV ENGINE NACELLE

File name: fogenpod  
Last revision: 4/13/97

BOTTOM WATERLINE

Segments: 4  
Fore end 16.5,20.4  
Aft end 18.2,18.6 21.0,16.8 31.0,15.75 43.0, 16.8  
Corner 16.6,19.6 19.15,17.35 23.8,15.9 35.6,15.65  
Curvature 0.79 0.83 0.72 0.73

WAIST WATERLINE

Segments: 1

Fore end 16.5,20.4  
Aft end 43.0,16.8  
Corner S  
Curvature

TOP WATERLINE

Segments: 4

Fore end 16.3,20.4  
Aft end 18.45,22.1 27.0,21.75 35.0,19.8 43.0,16.8  
Corner 16.75,21.3 21.4,22.5 30.4,21.3 38.3,18.75  
Curvature 0.79 0.80 0.70 0.75

MAXIMUM BUTTLINE DISTANCE FROM PLANE OF SYMMETRY

Segments: 4

Fore end 16.5,0  
Aft end 18.2,1.6 23.0,2.3 40.8,2.3 43.0,0  
Corner 16.5,0.70 20.1,2.25 S 43.0,2.3  
Curvature 0.72 0.75 0.90

BOTTOM K FACTOR

Segments: 4

Fore end 16.5,0.707  
Aft end 18.2,0.707  
Corner S 24.0,0.93 42.0,0.93 43.0,0.75  
Curvature 20.0,0.93 0.9 S

TOP K FACTOR

Segments: 4

Fore end 16.5,0.707  
Aft end 18.45,0.707 24.5,0.93 42.0,0.93  
Corner S 20.3,0.93 S  
Curvature 0.9

BUTTLINE AT PLANE OF SYMMETRY

Segments: 0

FOG UAV ENGINE PYLON (Lofted as A-Body Type)

File name: FOGPYLON  
Last revision: 4/13/97

Strips: 3  
Sym: Y

M1B

Segments: 1

Fore end 25.8,0  
Aft end 37.7,0  
Corner S  
K factor S

M1W

Segments: 1

Fore end 25.8,14.15  
Aft end 37.7,13.65  
Corner 29.4,15.45  
K factor 0.72

C1B

Segments: S

C1W

Segments: S

K1

Segments: S

M2B

Segments: 1

Fore end 25.8,0  
Aft end 37.7,0  
Corner 25.8,3.8  
K factor 0.71

M2W

Segments: =M1W

C2B

Segments: S

C2W

Segments: S

K2

Segments: S

M3B

Segments: =M2B

M3W

Segments: 1

Fore end 25.8,16.1  
Aft end 37.7,16.1  
Corner 33.65,15.35  
K factor 0.65

C3B

Segments: S

C3W

Segments: S

K3

Segments: S

M4B

Segments: =M1B

M4W

Segments: =M3W

**APPENDIX C**  
**FROG UAV CMARC INPUT FILE**



131

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10.0000      3.5900      0.4599
10.0000      3.6311      1.2505
10.0000      3.6402      2.7963
10.0000      3.6423      4.3120
10.0000      3.6428      5.8276
10.0000      3.6400      7.3433
10.0000      3.6087      8.4519
10.0000      3.5110      9.9679
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13.0902      3.0061      0.0077
13.0902      3.6868      0.0552
13.0902      3.8313      0.3019
13.0902      3.8583      1.3036
13.0902      3.8623      2.8174
13.0902      3.8633      4.3312
13.0902      3.8636      5.8451
13.0902      3.8614      7.3589
13.0902      3.8344      8.5203
13.0902      3.7416      9.0232
13.0902      3.4903      9.2092
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15.8779      4.0569      1.2775
15.8779      4.0614      2.8332
15.8779      4.0624      4.3890
15.8779      4.0627      5.9448
15.8779      4.0612      7.5006
15.8779      4.0415      8.8474
15.8779      3.9629      9.4248
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18.0902      4.2164      1.5673
18.0902      4.2198      3.2182
18.0902      4.2206      4.8691
18.0902      4.2207      6.5200

18.0902      4.2195      8.1710
18.0902      4.2094      9.8015
18.0902      4.1567      10.6520
18.0902      3.9490      10.8950
18.0902      3.2238      10.9567
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19.5106      4.3214      3.4275
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19.5106      4.3169      10.2448
19.5106      4.2840      11.4245
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20.0000      4.3535      1.7754
20.0000      4.3564      3.4956
20.0000      4.3571      5.2158
20.0000      4.3571      6.9360
20.0000      4.3562      8.6562
20.0000      4.3532      10.3763
20.0000      4.3272      11.6828
20.0000      4.1713      12.0088
20.0000      3.4117      12.0661
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20.0000      1.7202      0.0007
20.0000      3.4256      0.0081
20.0000      4.1917      0.0673
20.0000      4.3314      0.4135
20.0000      4.3535      1.7754
20.0000      4.3564      3.4956
20.0000      4.3571      5.2158
20.0000      4.3571      6.9360
20.0000      4.3562      8.6562
20.0000      4.3532      10.3763
20.0000      4.3272      11.6828
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20.0000      3.4117      12.0661
20.0000      1.7202      12.0742
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20.4440 4.3616 0.3949 0.0000
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21.6065 4.4441 0.3949 0.0000
21.6065 4.4680 1.7396 0.0000
21.6065 4.4711 3.4788 0.0000
21.6065 4.4718 5.2180 0.0000
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21.6065 4.3976 12.9316 0.0000
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23.0435 4.3384 0.0714 0.0000
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24.2060 4.4995 3.8970 0.0000
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24.2060 4.2423 13.9775 0.0000

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24.6500 4.3600 0.0829 0.0000
24.6500 4.4804 0.5384 0.0000
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24.6500 4.4995 3.9708 0.0000
24.6500 4.5000 5.7966 0.0000
24.6500 4.5000 7.6225 0.0000
24.6500 4.5000 9.4483 0.0000
24.6500 4.5000 11.2742 0.0000
24.6500 4.5000 13.1000 0.0000
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27.9487 4.4998 4.9237
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29.6349 4.4989 3.1333
29.6349 4.4998 4.8196
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33.5777 4.4943 1.3718
33.5777 4.4988 3.0430

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39.6047 4.4614 0.2944
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39.6047 4.4988 3.0452
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41.2909 3.3479 0.0061
41.2909 4.2720 0.0494
41.2909 4.4616 0.2971
41.2909 4.4943 1.3854
41.2909 4.4988 3.0593
41.2909 4.4998 4.7332
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42.6855 1.6764 0.0006

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TNODS=0, TNPS=0, TINTS=0, &END
43.7277 0.0000 0.0000
43.7277 1.6766 0.0007
43.7277 3.3528 0.0067
43.7277 4.2374 0.0530
43.7277 4.4194 0.3099
43.7277 4.4514 1.4174
43.7277 4.4558 3.0940
43.7277 4.4568 4.7706
43.7277 4.4570 6.4472
43.7277 4.4570 8.1238
43.7277 4.4570 9.8094
43.7277 4.4570 11.4770
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
44.3717 0.0000 0.0000
44.3717 1.6650 0.0097
44.3717 3.3021 0.0097
44.3717 4.0431 0.0680
44.3717 4.2033 0.3596
44.3717 4.2341 1.5030
44.3717 4.2388 3.1680
44.3717 4.2398 4.8331
44.3717 4.2400 6.4981
44.3717 4.2400 8.1631
44.3717 4.2400 9.8282
44.3717 4.2400 11.4932
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=3, TNPS=0, TINTS=0, &END
44.5909 0.0000 0.0000
44.5909 1.6672 0.0010
44.5909 3.2859 0.0111
44.5909 3.9797 0.0752
44.5909 4.1306 0.3843
44.5909 4.1604 1.5597
44.5909 4.1650 3.2268
44.5909 4.1660 4.8940
44.5909 4.1662 6.5612
44.5909 4.1662 8.2284
44.5909 4.1662 9.8955
44.5909 4.1662 11.5627
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

&PATCH1 IREV=0, IDPAT=2, MAKE=0, KCOMP=1, KASS=1, IPATCOP=0, &END
ROOT UPPER STARBOARD
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
24.6500 4.5000 13.1000
24.6500 4.2213 14.0848
24.6500 2.8142 14.0848
24.6500 1.4071 14.0848
24.6500 0.0000 14.0848
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
24.8679 4.5000 13.5517

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24.8679 4.2213 14.1334
24.8679 2.8142 14.1334
24.8679 1.4071 14.1334
24.8679 0.0000 14.1334
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
25.5119 4.5000 13.9485
25.5119 4.2213 14.2622
25.5119 2.8142 14.2622
25.5119 1.4071 14.2622
25.5119 0.0000 14.2622
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
26.5541 4.5000 14.2646
26.5541 4.2213 14.4272
26.5541 2.8142 14.4272
26.5541 1.4071 14.4272
26.5541 0.0000 14.4272
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
27.9487 4.5000 14.4706
27.9487 4.2213 14.5653
27.9487 2.8142 14.5653
27.9487 1.4071 14.5653
27.9487 0.0000 14.5653
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
29.6349 4.5000 14.5367
29.6349 4.2213 14.5971
29.6349 2.8142 14.5971
29.6349 1.4071 14.5971
29.6349 0.0000 14.5971
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
31.5390 4.5000 14.4449
31.5390 4.2213 14.5447
31.5390 2.8142 14.5447
31.5390 1.4071 14.5447
31.5390 0.0000 14.5447
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
33.5777 4.5000 14.2088
33.5777 4.2213 14.3864
33.5777 2.8142 14.3864
33.5777 1.4071 14.3864
33.5777 0.0000 14.3864
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
35.6619 4.5000 13.8627
35.6619 4.2213 14.0807
35.6619 2.8142 14.0807
35.6619 1.4071 14.0807
35.6619 0.0000 14.0807
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
37.7006 4.5000 13.4473
37.7006 4.2213 13.6423
37.7006 2.8142 13.6423
37.7006 1.4071 13.6423
37.7006 0.0000 13.6423
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,

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TNODS=0, TNPS=0, TINTS=0, &END
39.6047 4.5000 12.9980
39.6047 4.2213 13.1398
39.6047 2.8142 13.1398
39.6047 1.4071 13.1398
39.6047 0.0000 13.1398
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
41.2909 4.5000 12.5573
41.2909 4.2213 12.6458
41.2909 2.8142 12.6458
41.2909 1.4071 12.6458
41.2909 0.0000 12.6458
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
42.6855 4.5000 12.1606
42.6855 4.2213 12.2144
42.6855 2.8142 12.2144
42.6855 1.4071 12.2144
42.6855 0.0000 12.2144
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
43.7277 4.4570 11.8400
43.7277 4.1900 11.8826
43.7277 2.8142 11.8826
43.7277 1.4071 11.8826
43.7277 0.0000 11.8826
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
44.3717 4.2400 11.6336
44.3717 3.9900 11.6743
44.3717 2.8142 11.6743
44.3717 1.4071 11.6743
44.3717 0.0000 11.6743
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=3, TNPS=0, TINTS=0, &END
44.5909 4.1662 11.5627
44.5909 3.9300 11.6030
44.5909 2.8142 11.6030
44.5909 1.4071 11.6030
44.5909 0.0000 11.6030
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

&PATCH1 IREV=0, IDPAT=2, MAKE=0, KCOMP=1, KASS=1, IPATSW=1, IPATCOP=0, &END
ROOT TRANSITION AFT STARBORD
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
44.5909 0.0000 0.0000
44.5909 1.6672 0.0010
44.5909 3.2859 0.0111
44.5909 3.9797 0.0752
44.5909 4.1306 0.3843
44.5909 4.1604 1.5597
44.5909 4.1650 3.2268
44.5909 4.1660 4.8940
44.5909 4.1662 6.5612
44.5909 4.1662 8.2284
44.5909 4.1662 9.8955
44.5909 4.1662 11.5627
44.5909 3.9300 11.6030
44.5909 2.8142 11.6030
44.5909 1.4071 11.6030
44.5909 0.0000 11.6030
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,

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TNODS=0, TNPS=0, TINTS=0, &END
44.9164 0.0000 0.0000
44.9164 1.6527 0.0012
44.9164 3.2292 0.0128
44.9164 3.8750 0.0819
44.9164 4.0206 0.4023
44.9164 4.0505 1.5694
44.9164 4.0553 3.2220
44.9164 4.0564 4.8747
44.9164 4.0566 6.5274
44.9164 4.0566 8.1800
44.9164 4.0566 9.8327
44.9164 4.0562 11.4773
44.9164 3.8438 11.5962
44.9164 2.8142 11.5962
44.9164 1.4071 11.5962
44.9164 0.0000 11.5962
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
45.7687 0.0000 0.0000
45.7687 1.6149 0.0016
45.7687 3.0609 0.0178
45.7687 3.6006 0.1009
45.7687 3.7321 0.4387
45.7687 3.7625 1.5799
45.7687 3.7679 3.1948
45.7687 3.7692 4.8097
45.7687 3.7695 6.4245
45.7687 3.7695 8.0394
45.7687 3.7693 9.6543
45.7687 3.7674 11.2536
45.7687 3.5600 11.5767
45.7687 2.8142 11.5857
45.7687 1.4071 11.5860
45.7687 0.0000 11.5861
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
46.8222 0.0000 0.0000
46.8222 1.5638 0.0025
46.8222 2.8199 0.0253
46.8222 3.2590 0.1249
46.8222 3.3765 0.4866
46.8222 3.4068 1.5991
46.8222 3.4128 3.1628
46.8222 3.4143 4.7266
46.8222 3.4146 6.2903
46.8222 3.4146 7.8541
46.8222 3.4142 9.4178
46.8222 3.4111 10.9772
46.8222 3.3229 11.5231
46.8222 2.8650 11.5700
46.8222 1.4071 11.5733
46.8222 0.0000 11.5733
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
47.6745 0.0000 0.0000
47.6745 1.5223 0.0036
47.6745 2.6098 0.0323
47.6745 2.9827 0.1456
47.6745 3.0895 0.5253
47.6745 3.1192 1.6204
47.6745 3.1255 3.1427
47.6745 3.1271 4.6650
47.6745 3.1275 6.1873
47.6745 3.1275 7.7096
47.6745 3.1269 9.2319
47.6745 3.1232 10.7536

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47.6745 3.0838 11.4579
47.6745 2.7717 11.5525
47.6745 1.4071 11.5627
47.6745 0.0000 11.5634
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=3, TNPS=0, TINTS=0, &END
48.0000 0.0000 0.0000
48.0000 1.5058 0.0041
48.0000 2.5263 0.0352
48.0000 2.8769 0.1533
48.0000 2.9802 0.5421
48.0000 3.0094 1.6335
48.0000 3.0158 3.1393
48.0000 3.0175 4.6450
48.0000 3.0179 6.1508
48.0000 3.0178 7.6566
48.0000 3.0172 9.1624
48.0000 3.0134 10.6681
48.0000 2.9761 11.4292
48.0000 2.7054 11.5444
48.0000 1.4071 11.5586
48.0000 0.0000 11.5595
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&PATCH1 IREV=0, IDPAT=2, MAKE=0, KCOMP=1, KASS=1, IPATSYM=1, IPATCOP=0,
&END
FUSELAGE AFT
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
48.0000 0.0000 0.0000
48.0000 1.5058 0.0041
48.0000 2.5263 0.0352
48.0000 2.8769 0.1533
48.0000 2.9802 0.5421
48.0000 3.0094 1.6335
48.0000 3.0158 3.1393
48.0000 3.0175 4.6450
48.0000 3.0179 6.1508
48.0000 3.0178 7.6566
48.0000 3.0172 9.1624
48.0000 3.0134 10.6681
48.0000 2.9761 11.4292
48.0000 2.7054 11.5444
48.0000 1.5058 11.5586
48.0000 0.0000 11.5595
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
48.2093 0.0000 0.0000
48.2093 1.5001 0.0045
48.2093 2.4757 0.0375
48.2093 2.8105 0.1604
48.2093 2.9106 0.5614
48.2093 2.9390 1.6667
48.2093 2.9453 3.1668
48.2093 2.9469 4.6669
48.2093 2.9474 6.1670
48.2093 2.9473 7.6670
48.2093 2.9466 9.1671
48.2093 2.9424 10.6669
48.2093 2.9044 11.4175
48.2093 2.6462 11.5397
48.2093 1.4996 11.5559
48.2093 0.0000 11.5570
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
48.8055 0.0000 0.0000
48.8055 1.4733 0.0060

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48.8055 2.3269 0.0446
48.8055 2.6221 0.1829
48.8055 2.7120 0.6123
48.8055 2.7385 1.7484
48.8055 2.7445 3.2309
48.8055 2.7462 4.7134
48.8055 2.7466 6.1959
48.8055 2.7465 7.6784
48.8055 2.7456 9.1609
48.8055 2.7404 10.6408
48.8055 2.7016 11.3810
48.8055 2.4736 11.5252
48.8055 1.4808 11.5480
48.8055 0.0000 11.5499
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
49.6976 0.0000 0.0000
49.6976 1.3923 0.0085
49.6976 2.0943 0.0564
49.6976 2.1385 0.2185
49.6976 2.4154 0.6980
49.6976 2.4387 1.8818
49.6976 2.4441 3.3356
49.6976 2.4451 4.7894
49.6976 2.4459 6.2432
49.6976 2.4459 7.6970
49.6976 2.4448 9.1508
49.6976 2.4382 10.5961
49.6976 2.3990 11.3282
49.6976 2.2089 11.5012
49.6976 1.4448 11.5354
49.6976 0.0000 11.5393
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
50.7500 0.0000 0.0000
50.7500 1.2503 0.0119
50.7500 1.8087 0.0723
50.7500 2.0016 0.2624
50.7500 2.0654 0.8001
50.7500 2.0851 2.0280
50.7500 2.0898 3.4449
50.7500 2.0912 4.8618
50.7500 2.0916 6.2787
50.7500 2.0914 7.6956
50.7500 2.0900 9.1125
50.7500 2.0826 10.5181
50.7500 2.0449 11.2629
50.7500 1.8881 11.4705
50.7500 1.3215 11.5194
50.7500 0.0000 11.5268
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
51.8024 0.0000 0.0000
51.8024 1.0710 0.0155
51.8024 1.5126 0.0897
51.8024 1.6649 0.3144
51.8024 1.7158 0.9210
51.8024 1.7316 2.1843
51.8024 1.7355 3.5578
51.8024 1.7368 4.9313
51.8024 1.7371 6.3049
51.8024 1.7369 7.6784
51.8024 1.7353 9.0519
51.8024 1.7278 10.4187
51.8024 1.6936 11.1932
51.8024 1.5648 11.4376
51.8024 1.1343 11.5024

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51.8024      0.0000      11.5143
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
52.6945      0.0000      0.0000
52.6945      0.8991      0.0186
52.6945      1.2562      0.1053
52.6945      1.3782      0.3607
52.6945      1.4194      1.0318
52.6945      1.4320      2.3099
52.6945      1.4352      3.6427
52.6945      1.4363      4.9756
52.6945      1.4366      6.3084
52.6945      1.4363      7.6413
52.6945      1.4348      8.9741
52.6945      1.4280      10.3058
52.6945      1.3981      11.1267
52.6945      1.2909      11.4083
52.6945      0.9497      11.4877
52.6945      0.0000      11.5036
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
53.2907      0.0000      0.0142
53.2907      0.7868      0.0350
53.2907      1.0933      0.1303
53.2907      1.1979      0.4106
53.2907      1.2330      1.1338
53.2907      1.2435      2.4132
53.2907      1.2463      3.7174
53.2907      1.2472      5.0216
53.2907      1.2475      6.3259
53.2907      1.2472      7.6301
53.2907      1.2458      8.9343
53.2907      1.2394      10.2385
53.2907      1.2120      11.0812
53.2907      1.1171      11.3809
53.2907      0.8219      11.4693
53.2907      0.0000      11.4876
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=3, TNPS=0, TINTS=0, &END
53.5000      0.0000      5.7500
53.5000      0.0000      5.7539
53.5000      0.0000      5.7578
53.5000      0.0000      5.7852
53.5000      0.0000      5.8447
53.5000      0.0000      5.9043
53.5000      0.0000      5.9639
53.5000      0.0000      6.0234
53.5000      0.0000      6.0830
53.5000      0.0000      6.1426
53.5000      0.0000      6.2021
53.5000      0.0000      6.2617
53.5000      0.0000      6.3213
53.5000      0.0000      6.3809
53.5000      0.0000      6.4404
53.5000      0.0000      6.5000
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

&PATCH IREV=0, IPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSYM=1, IPATCOR=0, &END
INBOARD WING - 10X15
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
44.5909      4.1662      11.5627
44.3717      4.2400      11.4932
43.7277      4.4570      11.4770
42.6855      4.5000      11.4565
41.2909      4.5000      11.4290
39.6047      4.5000      11.4032

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37.7006      4.5000      11.3871
35.6619      4.5000      11.3790
33.5777      4.5000      11.3991
31.5390      4.5000      11.4614
29.6349      4.5000      11.5647
27.9487      4.5000      11.7283
26.5541      4.5000      11.9690
25.5119      4.5000      12.2862
24.8679      4.5000      12.6691
24.6500      4.5000      13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679      4.5000      13.5517
25.5119      4.5000      13.9485
26.5541      4.5000      14.2646
27.9487      4.5000      14.4706
29.6349      4.5000      14.5367
31.5390      4.5000      14.4449
33.5777      4.5000      14.2088
35.6619      4.5000      13.8627
37.7006      4.5000      13.4473
39.6047      4.5000      12.9980
41.2909      4.5000      12.5573
42.6855      4.5000      12.1606
43.7277      4.4570      11.8400
44.3717      4.2400      11.6336
44.5909      4.1662      11.5627
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODE=0, TNPS=0, TINTS=0, &END
44.5896      5.1607      11.5308
44.3717      5.1607      11.4914
43.7277      5.1607      11.4763
42.6855      5.1607      11.4563
41.2909      5.1607      11.4289
39.6047      5.1607      11.4032
37.7006      5.1607      11.3871
35.6619      5.1607      11.3790
33.5777      5.1607      11.3991
31.5390      5.1607      11.4614
29.6349      5.1607      11.5647
27.9487      5.1607      11.7283
26.5541      5.1607      11.9690
25.5119      5.1607      12.2862
24.8679      5.1607      12.6691
24.6500      5.1607      13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679      5.1607      13.5517
25.5119      5.1607      13.9485
26.5541      5.1607      14.2646
27.9487      5.1607      14.4706
29.6349      5.1607      14.5367
31.5390      5.1607      14.4449
33.5777      5.1607      14.2088
35.6619      5.1607      13.8627
37.7006      5.1607      13.4473
39.6047      5.1607      12.9980
41.2909      5.1607      12.5573
42.6855      5.1607      12.1607
43.7277      5.1607      11.8407
44.3717      5.1607      11.6352
44.5896      5.1607      11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
44.5896      7.0783      11.5308
44.3717      7.0783      11.4914
43.7277      7.0783      11.4763
42.6855      7.0783      11.4563
41.2909      7.0783      11.4289
39.6047      7.0783      11.4032

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37.7006 7.0783 11.3871
35.6619 7.0783 11.3790
33.5777 7.0783 11.3991
31.5390 7.0783 11.4614
29.6349 7.0783 11.5647
27.9487 7.0783 11.7283
26.5541 7.0783 11.9690
25.5119 7.0783 12.2862
24.8679 7.0783 12.6691
24.6500 7.0783 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 7.0783 13.5517
25.5119 7.0783 13.9485
26.5541 7.0783 14.2646
27.9487 7.0783 14.4706
29.6349 7.0783 14.5367
31.5390 7.0783 14.4449
33.5777 7.0783 14.2088
35.6619 7.0783 13.8627
37.7006 7.0783 13.4473
39.6047 7.0783 12.9980
41.2909 7.0783 12.5573
42.6855 7.0783 12.1607
43.7277 7.0783 11.8407
44.3717 7.0783 11.6352
44.5896 7.0783 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
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44.3717 10.0649 11.4914
43.7277 10.0649 11.4763
42.6855 10.0649 11.4563
41.2909 10.0649 11.4289
39.6047 10.0649 11.4032
37.7006 10.0649 11.3871
35.6619 10.0649 11.3790
33.5777 10.0649 11.3991
31.5390 10.0649 11.4614
29.6349 10.0649 11.5647
27.9487 10.0649 11.7283
26.5541 10.0649 11.9690
25.5119 10.0649 12.2862
24.8679 10.0649 12.6691
24.6500 10.0649 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 10.0649 13.5517
25.5119 10.0649 13.9485
26.5541 10.0649 14.2646
27.9487 10.0649 14.4706
29.6349 10.0649 14.5367
31.5390 10.0649 14.4449
33.5777 10.0649 14.2088
35.6619 10.0649 13.8627
37.7006 10.0649 13.4473
39.6047 10.0649 12.9980
41.2909 10.0649 12.5573
42.6855 10.0649 12.1607
43.7277 10.0649 11.8407
44.3717 10.0649 11.6352
44.5896 10.0649 11.5308
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TNODE=0, TNPS=0, TINTS=0, &END
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44.3717 13.8283 11.4914
43.7277 13.8283 11.4763
42.6855 13.8283 11.4563
41.2909 13.8283 11.4289
39.6047 13.8283 11.4032
37.7006 13.8283 11.3871
35.6619 13.8283 11.3790
33.5777 13.8283 11.3991
31.5390 13.8283 11.4614
29.6349 13.8283 11.5647
27.9487 13.8283 11.7283
26.5541 13.8283 11.9690
25.5119 13.8283 12.2862
24.8679 13.8283 12.6691
24.6500 13.8283 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 13.8283 13.5517
25.5119 13.8283 13.9485
26.5541 13.8283 14.2646
27.9487 13.8283 14.4706
29.6349 13.8283 14.5367
31.5390 13.8283 14.4449
33.5777 13.8283 14.2088
35.6619 13.8283 13.8627
37.7006 13.8283 13.4473
39.6047 13.8283 12.9980
41.2909 13.8283 12.5573
42.6855 13.8283 12.1607
43.7277 13.8283 11.8407
44.3717 13.8283 11.6352
44.5896 13.8283 11.5308
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44.5896 18.0000 11.5308
44.3717 18.0000 11.4914
43.7277 18.0000 11.4763
42.6855 18.0000 11.4563
41.2909 18.0000 11.4289
39.6047 18.0000 11.4032
37.7006 18.0000 11.3871
35.6619 18.0000 11.3790
33.5777 18.0000 11.3991
31.5390 18.0000 11.4614
29.6349 18.0000 11.5647
27.9487 18.0000 11.7283
26.5541 18.0000 11.9690
25.5119 18.0000 12.2862
24.8679 18.0000 12.6691
24.6500 18.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5119 18.0000 13.9485
26.5541 18.0000 14.2646
27.9487 18.0000 14.4706
29.6349 18.0000 14.5367
31.5390 18.0000 14.4449
33.5777 18.0000 14.2088
35.6619 18.0000 13.8627
37.7006 18.0000 13.4473
39.6047 18.0000 12.9980
41.2909 18.0000 12.5573
42.6855 18.0000 12.1607
43.7277 18.0000 11.8407
44.3717 18.0000 11.6352
44.5896 18.0000 11.5308
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TNODE=0, TNPS=0, TINTS=0, &END
44.5896 22.1717 11.5308
44.3717 22.1717 11.4914
43.7277 22.1717 11.4763
42.6855 22.1717 11.4563
41.2909 22.1717 11.4289
39.6047 22.1717 11.4032

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37.7006 13.8283 11.3871
35.6619 13.8283 11.3790
33.5777 13.8283 11.3991
31.5390 13.8283 11.4614
29.6349 13.8283 11.5647
27.9487 13.8283 11.7283
26.5541 13.8283 11.9690
25.5119 13.8283 12.2862
24.8679 13.8283 12.6691
24.6500 13.8283 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 13.8283 13.5517
25.5119 13.8283 13.9485
26.5541 13.8283 14.2646
27.9487 13.8283 14.4706
29.6349 13.8283 14.5367
31.5390 13.8283 14.4449
33.5777 13.8283 14.2088
35.6619 13.8283 13.8627
37.7006 13.8283 13.4473
39.6047 13.8283 12.9980
41.2909 13.8283 12.5573
42.6855 13.8283 12.1607
43.7277 13.8283 11.8407
44.3717 13.8283 11.6352
44.5896 13.8283 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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44.3717 18.0000 11.4914
43.7277 18.0000 11.4763
42.6855 18.0000 11.4563
41.2909 18.0000 11.4289
39.6047 18.0000 11.4032
37.7006 18.0000 11.3871
35.6619 18.0000 11.3790
33.5777 18.0000 11.3991
31.5390 18.0000 11.4614
29.6349 18.0000 11.5647
27.9487 18.0000 11.7283
26.5541 18.0000 11.9690
25.5119 18.0000 12.2862
24.8679 18.0000 12.6691
24.6500 18.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 18.0000 13.5517
25.5119 18.0000 13.9485
26.5541 18.0000 14.2646
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29.6349 18.0000 14.5367
31.5390 18.0000 14.4449
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39.6047 18.0000 12.9980
41.2909 18.0000 12.5573
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TNODE=0, TNPS=0, TINTS=0, &END
44.5896 22.1717 11.5308
44.3717 22.1717 11.4914
43.7277 22.1717 11.4763
42.6855 22.1717 11.4563
41.2909 22.1717 11.4289
39.6047 22.1717 11.4032

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37.7006 31.5000 11.3871
35.6619 31.5000 11.3790
31.5777 31.5000 11.3991
31.5390 31.5000 11.4614
29.6349 31.5000 11.5647
27.9487 31.5000 11.7283
26.5541 31.5000 11.9690
25.5119 31.5000 12.2862
24.8679 31.5000 12.6691
24.6500 31.5000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 31.5000 13.5517
25.5119 31.5000 13.9485
26.5541 31.5000 14.2646
27.9487 31.5000 14.4706
29.6349 31.5000 14.5367
31.5390 31.5000 14.4449
33.5777 31.5000 14.2088
35.6619 31.5000 13.8627
37.7006 31.5000 13.4473
39.6047 31.5000 12.9980
41.2909 31.5000 12.5573
42.6855 31.5000 12.1607
43.7277 31.5000 11.8407
44.3717 31.5000 11.6352
44.5896 31.5000 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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&RECT ALL- NO DEFLECTION (10X15)
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TNODES=0, TNPS=0, TINTS=0, &END
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44.3717 31.5000 11.4932
43.7277 31.5000 11.4770
42.6855 31.5000 11.4565
41.2909 31.5000 11.4290
39.6047 31.5000 11.4032
37.7006 31.5000 11.3871
35.6619 31.5000 11.3790
33.5777 31.5000 11.3991
31.5390 31.5000 11.4614
29.6349 31.5000 11.5647
27.9487 31.5000 11.7283
26.5541 31.5000 11.9690
25.5119 31.5000 12.2862
24.8679 31.5000 12.6691
24.6500 31.5000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 31.5000 13.5517
25.5119 31.5000 13.9485
26.5541 31.5000 14.2646
27.9487 31.5000 14.4706
29.6349 31.5000 14.5367
31.5390 31.5000 14.4449
33.5777 31.5000 14.2088
35.6619 31.5000 13.8627
37.7006 31.5000 13.4473
39.6047 31.5000 12.9980
41.2909 31.5000 12.5573
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TNODES=0, TNPS=0, TINTS=0, &END
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44.4315 32.0261 11.4948
43.7855 32.0261 11.4783

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```

42.7402 32.0261 11.4575
41.1500 32.0261 11.4266
39.6500 32.0261 11.4037
37.7402 32.0261 11.3873
35.6953 32.0261 11.3790
33.6047 32.0261 11.3986
31.5598 32.0261 11.4606
29.6500 32.0261 11.5637
27.9587 32.0261 11.7270
26.5598 32.0261 11.9677
25.5145 32.0261 12.2851
24.8685 32.0261 12.6685
24.6500 32.0261 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 32.0261 13.9496
26.5598 32.0261 14.2658
27.9587 32.0261 14.4714
29.6500 32.0261 14.5366
31.5598 32.0261 14.4431
33.6047 32.0261 14.2049
35.6953 32.0261 13.8565
37.7402 32.0261 13.4385
39.6500 32.0261 12.9867
41.3413 32.0261 12.5435
42.7402 32.0261 12.1443
43.7855 32.0261 11.8217
44.4315 32.0261 11.6143
44.5896 32.0261 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
44.5896 33.5531 11.5308
44.4315 33.5531 11.4948
43.7855 33.5531 11.4783
42.7402 33.5531 11.4575
41.1500 33.5531 11.4266
39.6500 33.5531 11.4037
37.7402 33.5531 11.3873
35.6953 33.5531 11.3790
33.6047 33.5531 11.3986
31.5598 33.5531 11.4606
29.6500 33.5531 11.5637
27.9587 33.5531 11.7270
26.5598 33.5531 11.9677
25.5145 33.5531 12.2851
24.8685 33.5531 12.6685
24.6500 33.5531 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 33.5531 13.5524
25.5145 33.5531 13.9496
26.5598 33.5531 14.2658
27.9587 33.5531 14.4714
29.6500 33.5531 14.5366
31.5598 33.5531 14.4431
33.6047 33.5531 14.2049
35.6953 33.5531 13.8565
37.7402 33.5531 13.4385
39.6500 33.5531 12.9867
41.3413 33.5531 12.5435
42.7402 33.5531 12.1443
43.7855 33.5531 11.8217
44.4315 33.5531 11.6143
44.5896 33.5531 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
44.5896 35.9313 11.5308
44.4315 35.9313 11.4948
43.7855 35.9313 11.4783

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42.7402 48.5687 11.4575
41.1500 48.5687 11.4266
39.6500 48.5687 11.4037
37.7402 48.5687 11.3873
35.6953 48.5687 11.3790
33.6047 48.5687 11.3986
31.5598 48.5687 11.4606
29.6500 48.5687 11.5637
27.9587 48.5687 11.7270
26.5598 48.5687 11.9677
25.5145 48.5687 12.2851
24.8685 48.5687 12.6685
24.6500 48.5687 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 48.5687 13.5524
25.5145 48.5687 13.9496
26.5598 48.5687 14.2658
27.9587 48.5687 14.4714
29.6500 48.5687 14.5366
31.5598 48.5687 14.4431
33.6047 48.5687 14.2049
35.6953 48.5687 13.8565
37.7402 48.5687 13.4385
39.6500 48.5687 12.9867
41.3413 48.5687 12.5435
42.7402 48.5687 12.1443
43.7855 48.5687 11.8217
44.4315 48.5687 11.6143
44.5896 48.5687 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODE=0, TNPS=0, TINTS=0, &END
44.5896 50.9469 11.5308
44.4315 50.9469 11.4948
43.7855 50.9469 11.4783
42.7402 50.9469 11.4575
41.1500 50.9469 11.4266
39.6500 50.9469 11.4037
37.7402 50.9469 11.3873
35.6953 50.9469 11.3790
33.6047 50.9469 11.3986
31.5598 50.9469 11.4606
29.6500 50.9469 11.5637
27.9587 50.9469 11.7270
26.5598 50.9469 11.9677
25.5145 50.9469 12.2851
24.8685 50.9469 12.6685
24.6500 50.9469 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 50.9469 13.5524
25.5145 50.9469 13.9496
26.5598 50.9469 14.2658
27.9587 50.9469 14.4714
29.6500 50.9469 14.5366
31.5598 50.9469 14.4431
33.6047 50.9469 14.2049
35.6953 50.9469 13.8565
37.7402 50.9469 13.4385
39.6500 50.9469 12.9867
41.3413 50.9469 12.5435
42.7402 50.9469 12.1443
43.7855 50.9469 11.8217
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44.5896 50.9469 11.5308
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TNODE=0, TNPS=0, TINTS=0, &END
44.5896 52.4739 11.5308
44.4315 52.4739 11.4948
43.7855 52.4739 11.4783
42.7402 52.4739 11.4575
41.1500 52.4739 11.4266
39.6500 52.4739 11.4037
37.7402 52.4739 11.3873
35.6953 52.4739 11.3790
33.6047 52.4739 11.3986
31.5598 52.4739 11.4606
29.6500 52.4739 11.5637
27.9587 52.4739 11.7270
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25.5145 52.4739 12.2851
24.8685 52.4739 12.6685
24.6500 52.4739 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 52.4739 13.9496
26.5598 52.4739 14.2658
27.9587 52.4739 14.4714
29.6500 52.4739 14.5366
31.5598 52.4739 14.4431
33.6047 52.4739 14.2049
35.6953 52.4739 13.8565
37.7402 52.4739 13.4385
39.6500 52.4739 12.9867
41.3413 52.4739 12.5435
42.7402 52.4739 12.1443
43.7855 52.4739 11.8217
44.4315 52.4739 11.6143
44.5896 52.4739 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
44.5896 53.0000 11.5308
44.3717 53.0000 11.4932
43.7277 53.0000 11.4770
42.6855 53.0000 11.4565
41.2909 53.0000 11.4290
39.6047 53.0000 11.4032
37.7006 53.0000 11.3871
35.6619 53.0000 11.3790
33.5777 53.0000 11.3991
31.5390 53.0000 11.4614
29.6349 53.0000 11.5647
27.9487 53.0000 11.7283
26.5541 53.0000 11.9690
25.5119 53.0000 12.2862
24.8679 53.0000 12.6691
24.6500 53.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5119 53.0000 13.9485
26.5541 53.0000 14.2646
27.9487 53.0000 14.4706
29.6349 53.0000 14.5367
31.5390 53.0000 14.4449
33.5777 53.0000 14.2088
35.6619 53.0000 13.8627
37.7006 53.0000 13.4473
39.6047 53.0000 12.9980
41.2909 53.0000 12.5573
42.6855 53.0000 12.1606
43.7277 53.0000 11.8400
44.3717 53.0000 11.6336
44.5896 53.0000 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&PATCH IREV=-1, IDPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSW=0, IPATCOP=0, &END
LEFT AIL NO DEFLECTION 10X15
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END

```

```

42.7402 52.4739 11.4575
41.1500 52.4739 11.4266
39.6500 52.4739 11.4037
37.7402 52.4739 11.3873
35.6953 52.4739 11.3790
33.6047 52.4739 11.3986
31.5598 52.4739 11.4606
29.6500 52.4739 11.5637
27.9587 52.4739 11.7270
26.5598 52.4739 11.9677
25.5145 52.4739 12.2851
24.8685 52.4739 12.6685
24.6500 52.4739 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 52.4739 13.5524
25.5145 52.4739 13.9496
26.5598 52.4739 14.2658
27.9587 52.4739 14.4714
29.6500 52.4739 14.5366
31.5598 52.4739 14.4431
33.6047 52.4739 14.2049
35.6953 52.4739 13.8565
37.7402 52.4739 13.4385
39.6500 52.4739 12.9867
41.3413 52.4739 12.5435
42.7402 52.4739 12.1443
43.7855 52.4739 11.8217
44.4315 52.4739 11.6143
44.5896 52.4739 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
44.5896 53.0000 11.5308
44.3717 53.0000 11.4932
43.7277 53.0000 11.4770
42.6855 53.0000 11.4565
41.2909 53.0000 11.4290
39.6047 53.0000 11.4032
37.7006 53.0000 11.3871
35.6619 53.0000 11.3790
33.5777 53.0000 11.3991
31.5390 53.0000 11.4614
29.6349 53.0000 11.5647
27.9487 53.0000 11.7283
26.5541 53.0000 11.9690
25.5119 53.0000 12.2862
24.8679 53.0000 12.6691
24.6500 53.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 53.0000 13.5517
25.5119 53.0000 13.9485
26.5541 53.0000 14.2646
27.9487 53.0000 14.4706
29.6349 53.0000 14.5367
31.5390 53.0000 14.4449
33.5777 53.0000 14.2088
35.6619 53.0000 13.8627
37.7006 53.0000 13.4473
39.6047 53.0000 12.9980
41.2909 53.0000 12.5573
42.6855 53.0000 12.1606
43.7277 53.0000 11.8400
44.3717 53.0000 11.6336
44.5896 53.0000 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

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&PATCH IREV=-1, IDPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSW=0, IPATCOP=0, &END
LEFT AIL NO DEFLECTION 10X15
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END

```

```

44.5896 -31.5000 11.5308
44.3717 -31.5000 11.4932
43.7277 -31.5000 11.4770
42.6855 -31.5000 11.4565
41.2909 -31.5000 11.4290
39.6047 -31.5000 11.4032
37.7006 -31.5000 11.3871
35.6619 -31.5000 11.3790
33.5777 -31.5000 11.3991
31.5390 -31.5000 11.4614
29.6349 -31.5000 11.5647
27.9487 -31.5000 11.7283
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25.5119 -31.5000 12.2862
24.8679 -31.5000 12.6691
24.6500 -31.5000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 -31.5000 13.5517
25.5119 -31.5000 13.9485
26.5541 -31.5000 14.2646
27.9487 -31.5000 14.4706
29.6349 -31.5000 14.5367
31.5390 -31.5000 14.4449
33.5777 -31.5000 14.2088
35.6619 -31.5000 13.8627
37.7006 -31.5000 13.4473
39.6047 -31.5000 12.9980
41.2909 -31.5000 12.5573
42.6855 -31.5000 12.1606
43.7277 -31.5000 11.8400
44.3717 -31.5000 11.6336
44.5896 -31.5000 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
44.5896 -32.0261 11.5308
44.4315 -32.0261 11.4948
43.7855 -32.0261 11.4783
42.7402 -32.0261 11.4575
40.9000 -32.0261 11.4223
39.6500 -32.0261 11.4037
37.7402 -32.0261 11.3873
35.6953 -32.0261 11.3790
33.6047 -32.0261 11.3986
31.5598 -32.0261 11.4606
29.6500 -32.0261 11.5637
27.9587 -32.0261 11.7270
26.5598 -32.0261 11.9677
25.5145 -32.0261 12.2851
24.8685 -32.0261 12.6685
24.6500 -32.0261 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 -32.0261 13.5524
25.5145 -32.0261 13.9496
26.5598 -32.0261 14.2658
27.9587 -32.0261 14.4714
29.6500 -32.0261 14.5366
31.5598 -32.0261 14.4431
33.6047 -32.0261 14.2049
35.6953 -32.0261 13.8565
37.7402 -32.0261 13.4385
39.6500 -32.0261 12.9867
41.3413 -32.0261 12.5435
42.7402 -32.0261 12.1443
43.7855 -32.0261 11.8217
44.4315 -32.0261 11.6143
44.5896 -32.0261 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END

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```

44.5896 -33.5531 11.5308
44.4315 -33.5531 11.4948
43.7855 -33.5531 11.4783
42.7402 -33.5531 11.4575
40.9000 -33.5531 11.4223
39.6500 -33.5531 11.4037
37.7402 -33.5531 11.3873
35.6953 -33.5531 11.3790
33.6047 -33.5531 11.3986
31.5598 -33.5531 11.4606
29.6500 -33.5531 11.5637
27.9587 -33.5531 11.7270
26.5598 -33.5531 11.9677
25.5145 -33.5531 12.2851
24.8685 -33.5531 12.6685
24.6500 -33.5531 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 -33.5531 13.5524
25.5145 -33.5531 13.9496
26.5598 -33.5531 14.2658
27.9587 -33.5531 14.4714
29.6500 -33.5531 14.5366
31.5598 -33.5531 14.4431
33.6047 -33.5531 14.2049
35.6953 -33.5531 13.8565
37.7402 -33.5531 13.4385
39.6500 -33.5531 12.9867
41.3413 -33.5531 12.5435
42.7402 -33.5531 12.1443
43.7855 -33.5531 11.8217
44.4315 -33.5531 11.6143
44.5896 -33.5531 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
44.5896 -35.9313 11.5308
44.4315 -35.9313 11.4948
43.7855 -35.9313 11.4783
42.7402 -35.9313 11.4575
40.9000 -35.9313 11.4223
39.6500 -35.9313 11.4037
37.7402 -35.9313 11.3873
35.6953 -35.9313 11.3790
33.6047 -35.9313 11.3986
31.5598 -35.9313 11.4606
29.6500 -35.9313 11.5637
27.9587 -35.9313 11.7270
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25.5145 -35.9313 12.2851
24.8685 -35.9313 12.6685
24.6500 -35.9313 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 -35.9313 13.9496
26.5598 -35.9313 14.2658
27.9587 -35.9313 14.4714
29.6500 -35.9313 14.5366
31.5598 -35.9313 14.4431
33.6047 -35.9313 14.2049
35.6953 -35.9313 13.8565
37.7402 -35.9313 13.4385
39.6500 -35.9313 12.9867
41.3413 -35.9313 12.5435
42.7402 -35.9313 12.1443
43.7855 -35.9313 11.8217
44.4315 -35.9313 11.6143
44.5896 -35.9313 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODS=0, TNPS=0, TINTS=0, &END

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```

44.5896 -38.9281 11.5308
44.4315 -38.9281 11.4948
43.7855 -38.9281 11.4783
42.7402 -38.9281 11.4575
40.9000 -38.9281 11.4223
39.6500 -38.9281 11.4037
37.7402 -38.9281 11.3873
35.6953 -38.9281 11.3790
33.6047 -38.9281 11.3986
31.5598 -38.9281 11.4606
29.6500 -38.9281 11.5637
27.9587 -38.9281 11.7270
26.5598 -38.9281 11.9677
25.5145 -38.9281 12.2851
24.8685 -38.9281 12.6685
24.6500 -38.9281 13.1000
&BNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 -38.9281 13.9496
26.5598 -38.9281 14.2658
27.9587 -38.9281 14.4714
29.6500 -38.9281 14.5366
31.5598 -38.9281 14.4431
33.6047 -38.9281 14.2049
35.6953 -38.9281 13.8565
37.7402 -38.9281 13.4385
39.6500 -38.9281 12.9867
41.3413 -38.9281 12.5435
42.7402 -38.9281 12.1443
43.7855 -38.9281 11.8217
44.4315 -38.9281 11.6143
44.5896 -38.9281 11.5308
&BNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
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44.4315 -42.2500 11.4948
43.7855 -42.2500 11.4783
42.7402 -42.2500 11.4575
40.9000 -42.2500 11.4223
39.6500 -42.2500 11.4037
37.7402 -42.2500 11.3873
35.6953 -42.2500 11.3790
33.6047 -42.2500 11.3986
31.5598 -42.2500 11.4606
29.6500 -42.2500 11.5637
27.9587 -42.2500 11.7270
26.5598 -42.2500 11.9677
25.5145 -42.2500 12.2851
24.8685 -42.2500 12.6685
24.6500 -42.2500 13.1000
&BNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 -42.2500 13.9496
26.5598 -42.2500 14.2658
27.9587 -42.2500 14.4714
29.6500 -42.2500 14.5366
31.5598 -42.2500 14.4431
33.6047 -42.2500 14.2049
35.6953 -42.2500 13.8565
37.7402 -42.2500 13.4385
39.6500 -42.2500 12.9867
41.3413 -42.2500 12.5435
42.7402 -42.2500 12.1443
43.7855 -42.2500 11.8217
44.4315 -42.2500 11.6143
44.5896 -42.2500 11.5308
&BNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=0, TNPS=0, TINTS=0, &END

```

```

44.5896 -45.5719 11.5308
44.4315 -45.5719 11.4948
43.7855 -45.5719 11.4783
42.7402 -45.5719 11.4575
40.9000 -45.5719 11.4223
39.6500 -45.5719 11.4037
37.7402 -45.5719 11.3873
35.6953 -45.5719 11.3790
33.6047 -45.5719 11.3986
31.5598 -45.5719 11.4606
29.6500 -45.5719 11.5637
27.9587 -45.5719 11.7270
26.5598 -45.5719 11.9677
25.5145 -45.5719 12.2851
24.8685 -45.5719 12.6685
24.6500 -45.5719 13.1000
&BNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 -45.5719 13.9496
26.5598 -45.5719 14.2658
27.9587 -45.5719 14.4714
29.6500 -45.5719 14.5366
31.5598 -45.5719 14.4431
33.6047 -45.5719 14.2049
35.6953 -45.5719 13.8565
37.7402 -45.5719 13.4385
39.6500 -45.5719 12.9867
41.3413 -45.5719 12.5435
42.7402 -45.5719 12.1443
43.7855 -45.5719 11.8217
44.4315 -45.5719 11.6143
44.5896 -45.5719 11.5308
&BNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
44.5896 -48.5687 11.5308
44.4315 -48.5687 11.4948
43.7855 -48.5687 11.4783
42.7402 -48.5687 11.4575
40.9000 -48.5687 11.4223
39.6500 -48.5687 11.4037
37.7402 -48.5687 11.3873
35.6953 -48.5687 11.3790
33.6047 -48.5687 11.3986
31.5598 -48.5687 11.4606
29.6500 -48.5687 11.5637
27.9587 -48.5687 11.7270
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25.5145 -48.5687 12.2851
24.8685 -48.5687 12.6685
24.6500 -48.5687 13.1000
&BNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 -48.5687 13.9496
26.5598 -48.5687 14.2658
27.9587 -48.5687 14.4714
29.6500 -48.5687 14.5366
31.5598 -48.5687 14.4431
33.6047 -48.5687 14.2049
35.6953 -48.5687 13.8565
37.7402 -48.5687 13.4385
39.6500 -48.5687 12.9867
41.3413 -48.5687 12.5435
42.7402 -48.5687 12.1443
43.7855 -48.5687 11.8217
44.4315 -48.5687 11.6143
44.5896 -48.5687 11.5308
&BNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=0, TNPS=0, TINTS=0, &END

```

```

44.5896 -50.9469 11.5308
44.4315 -50.9469 11.4948
43.7855 -50.9469 11.4783
42.7402 -50.9469 11.4575
40.9000 -50.9469 11.4223
39.6500 -50.9469 11.4037
37.7402 -50.9469 11.3873
35.6953 -50.9469 11.3790
33.6047 -50.9469 11.3986
31.5598 -50.9469 11.4606
29.6500 -50.9469 11.5357
27.9587 -50.9469 11.7270
26.5598 -50.9469 11.9677
25.5145 -50.9469 12.2851
24.8685 -50.9469 12.6685
24.6500 -50.9469 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 -50.9469 13.5524
25.5145 -50.9469 13.9496
26.5598 -50.9469 14.2658
27.9587 -50.9469 14.4714
29.6500 -50.9469 14.5366
31.5598 -50.9469 14.4431
33.6047 -50.9469 14.2049
35.6953 -50.9469 13.8565
37.7402 -50.9469 13.4385
39.6500 -50.9469 12.9867
41.3413 -50.9469 12.5435
42.7402 -50.9469 12.1443
43.7855 -50.9469 11.8217
44.4315 -50.9469 11.6143
44.5896 -50.9469 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
44.5896 -52.4739 11.5308
44.4315 -52.4739 11.4948
43.7855 -52.4739 11.4783
42.7402 -52.4739 11.4575
40.9000 -52.4739 11.4223
39.6500 -52.4739 11.4037
37.7402 -52.4739 11.3873
35.6953 -52.4739 11.3790
33.6047 -52.4739 11.3986
31.5598 -52.4739 11.4606
29.6500 -52.4739 11.5637
27.9587 -52.4739 11.7270
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25.5145 -52.4739 12.2851
24.8685 -52.4739 12.6685
24.6500 -52.4739 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.5145 -52.4739 13.9496
26.5598 -52.4739 14.2658
27.9587 -52.4739 14.4714
29.6500 -52.4739 14.5366
31.5598 -52.4739 14.4431
33.6047 -52.4739 14.2049
35.6953 -52.4739 13.8565
37.7402 -52.4739 13.4385
39.6500 -52.4739 12.9867
41.3413 -52.4739 12.5435
42.7402 -52.4739 12.1443
43.7855 -52.4739 11.8217
44.4315 -52.4739 11.6143
44.5896 -52.4739 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=3, TNPS=0, TINTS=0, &END

```

```

44.5896 -53.0000 11.5308
44.3717 -53.0000 11.4932
43.7277 -53.0000 11.4770
42.6855 -53.0000 11.4565
41.2909 -53.0000 11.4290
39.6047 -53.0000 11.4032
37.7006 -53.0000 11.3871
35.6619 -53.0000 11.3790
33.5777 -53.0000 11.3991
31.5390 -53.0000 11.4614
29.6349 -53.0000 11.5647
27.9487 -53.0000 11.7283
26.5541 -53.0000 11.9690
25.5119 -53.0000 12.2862
24.8679 -53.0000 12.6691
24.6500 -53.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 -53.0000 13.5517
25.5119 -53.0000 13.9485
26.5541 -53.0000 14.2646
27.9487 -53.0000 14.4706
29.6349 -53.0000 14.5367
31.5390 -53.0000 14.4449
33.5777 -53.0000 14.2088
35.6619 -53.0000 13.8627
37.7006 -53.0000 13.4473
39.6047 -53.0000 12.9980
41.2909 -53.0000 12.5573
42.6855 -53.0000 12.1607
43.7277 -53.0000 11.8407
44.3717 -53.0000 11.6352
44.5896 -53.0000 11.5308
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&PATCH1 IRV=0, IDPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSYM=1, IPATCOP=0, &END
WING OUTBOARD TAPERED- 6X15
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
44.5896 -53.0000 11.5308
44.3717 -53.0000 11.4914
43.7277 -53.0000 11.4763
42.6855 -53.0000 11.4563
41.2909 -53.0000 11.4289
39.6047 -53.0000 11.4032
37.7006 -53.0000 11.3871
35.6619 -53.0000 11.3790
33.5777 -53.0000 11.3991
31.5390 -53.0000 11.4614
29.6349 -53.0000 11.5647
27.9487 -53.0000 11.7283
26.5541 -53.0000 11.9690
25.5119 -53.0000 12.2862
24.8679 -53.0000 12.6691
24.6500 -53.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8679 -53.0000 13.5517
25.5119 -53.0000 13.9485
26.5541 -53.0000 14.2646
27.9487 -53.0000 14.4706
29.6349 -53.0000 14.5367
31.5390 -53.0000 14.4449
33.5777 -53.0000 14.2088
35.6619 -53.0000 13.8627
37.7006 -53.0000 13.4473
39.6047 -53.0000 12.9980
41.2909 -53.0000 12.5573
42.6855 -53.0000 12.1607
43.7277 -53.0000 11.8407
44.3717 -53.0000 11.6352
44.5896 -53.0000 11.5308

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&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
44.4894 53.5359 11.5387
44.4894 53.5359 11.5387
44.2727 53.5359 11.4994
43.6318 53.5359 11.4845
42.5949 53.5359 11.4646
41.2073 53.5359 11.4373
39.5296 53.5359 11.4117
37.6351 53.5359 11.3957
35.6066 53.5359 11.3877
33.5328 53.5359 11.4077
31.5044 53.5359 11.4697
29.6099 53.5359 11.5724
27.9321 53.5359 11.7352
26.5445 53.5359 11.9747
25.5076 53.5359 12.2903
24.8668 53.5359 12.6713
24.6500 53.5359 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8668 53.5359 13.5495
25.5076 53.5359 13.9442
26.5445 53.5359 14.2588
27.9321 53.5359 14.4637
29.6099 53.5359 14.5294
31.5044 53.5359 14.4381
33.5328 53.5359 14.2033
35.6066 53.5359 13.8589
37.6351 53.5359 13.4455
39.5296 53.5359 12.9985
41.2073 53.5359 12.5600
42.5949 53.5359 12.1654
43.6318 53.5359 11.8470
44.2727 53.5359 11.6426
44.4894 53.5359 11.5387
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
44.2157 55.0000 11.5602
44.0020 55.0000 11.5215
43.3700 55.0000 11.5068
42.3474 55.0000 11.4872
40.9789 55.0000 11.4603
39.3243 55.0000 11.4350
37.4559 55.0000 11.4192
35.4555 55.0000 11.4113
33.4103 55.0000 11.4310
31.4098 55.0000 11.4922
29.5414 55.0000 11.5935
27.8869 55.0000 11.7540
26.5184 55.0000 11.9902
25.4958 55.0000 12.3015
24.8638 55.0000 12.6772
24.6500 55.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8638 55.0000 13.5433
25.4958 55.0000 13.9326
26.5184 55.0000 14.2428
27.8869 55.0000 14.4449
29.5414 55.0000 14.5097
31.4098 55.0000 14.4196
33.4103 55.0000 14.1881
35.4555 55.0000 13.8484
37.4559 55.0000 13.4407
39.3243 55.0000 12.9999
40.9789 55.0000 12.5675
42.3474 55.0000 12.1783
43.3700 55.0000 11.8643
44.0020 55.0000 11.6627
44.2157 55.0000 11.5602

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&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
43.8419 57.0000 11.5897
43.6322 57.0000 11.5517
43.0123 57.0000 11.5372
42.0092 57.0000 11.5180
40.6669 57.0000 11.4916
39.0439 57.0000 11.4668
37.2112 57.0000 11.4513
35.2490 57.0000 11.4436
33.2429 57.0000 11.4629
31.2806 57.0000 11.5229
29.4480 57.0000 11.6223
27.8250 57.0000 11.7798
26.4827 57.0000 12.0114
25.4796 57.0000 12.3168
24.8597 57.0000 12.6853
24.6500 57.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.4796 57.0000 13.9167
26.4827 57.0000 14.2209
27.8250 57.0000 14.4192
29.4480 57.0000 14.4828
31.2806 57.0000 14.3944
33.2429 57.0000 14.1673
35.2490 57.0000 13.8341
37.2112 57.0000 13.4342
39.0439 57.0000 13.0018
40.6669 57.0000 12.5777
42.0092 57.0000 12.1959
43.0123 57.0000 11.8879
43.6322 57.0000 11.6901
43.8419 57.0000 11.5897
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
43.4680 59.0000 11.6191
43.2624 59.0000 11.5819
42.6545 59.0000 11.5676
41.6710 59.0000 11.5488
40.3548 59.0000 11.5229
38.7635 59.0000 11.4986
36.9665 59.0000 11.4834
35.0425 59.0000 11.4758
33.0755 59.0000 11.4948
31.1515 59.0000 11.5536
29.3545 59.0000 11.6511
27.7632 59.0000 11.8055
26.4470 59.0000 12.0326
25.4635 59.0000 12.3120
24.8556 59.0000 12.6333
24.6500 59.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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25.4635 59.0000 13.9007
26.4470 59.0000 14.1991
27.7632 59.0000 14.3935
29.3545 59.0000 14.4559
31.1515 59.0000 14.3692
33.0755 59.0000 14.1465
35.0425 59.0000 13.8198
36.9665 59.0000 13.4277
38.7635 59.0000 13.0037
40.3548 59.0000 12.5878
41.6710 59.0000 12.2135
42.6545 59.0000 11.9115
43.2624 59.0000 11.7176
43.4680 59.0000 11.6191

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&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
43.1943 60.4641 11.6406
42.9917 60.4641 11.6039
42.3927 60.4641 11.5899
41.4235 60.4641 11.5714
40.1264 60.4641 11.5459
38.5582 60.4641 11.5219
36.7874 60.4641 11.5069
34.8914 60.4641 11.4995
32.9530 60.4641 11.5181
31.0569 60.4641 11.5761
29.2861 60.4641 11.6721
27.7179 60.4641 11.8243
26.4208 60.4641 12.0481
25.4516 60.4641 12.3432
24.8526 60.4641 12.6993
24.6500 60.4641 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8526 60.4641 13.5201
25.4516 60.4641 13.8891
26.4208 60.4641 14.1831
27.7179 60.4641 14.3747
29.2861 60.4641 14.4361
31.0569 60.4641 14.3507
32.9530 60.4641 14.1313
34.8914 60.4641 13.8093
36.7874 60.4641 13.4230
38.5582 60.4641 13.0051
40.1264 60.4641 12.5953
41.4235 60.4641 12.2664
42.3927 60.4641 11.9288
42.9917 60.4641 11.7377
43.1943 60.4641 11.6406
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=3, TNPS=0, TINTS=0, &END
43.0941 61.0000 11.6485
42.8926 61.0000 11.6120
42.2968 61.0000 11.5981
41.3329 61.0000 11.5796
40.0428 61.0000 11.5543
38.4831 61.0000 11.5304
36.7218 61.0000 11.5156
34.8360 61.0000 11.5081
32.9081 61.0000 11.5267
31.0223 61.0000 11.5843
29.2610 61.0000 11.6799
27.7013 61.0000 11.8312
26.4113 61.0000 12.0538
25.4473 61.0000 12.3473
24.8515 61.0000 12.7014
24.6500 61.0000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8515 61.0000 13.5178
25.4473 61.0000 13.8848
26.4113 61.0000 14.1773
27.7013 61.0000 14.3678
29.2610 61.0000 14.4289
31.0223 61.0000 14.3440
32.9081 61.0000 14.1257
34.8360 61.0000 13.8055
36.7218 61.0000 13.4212
38.4831 61.0000 13.0057
40.0428 61.0000 12.5980
41.3329 61.0000 12.2311
42.2968 61.0000 11.9351
42.8926 61.0000 11.7451
43.0941 61.0000 11.6485

&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&PATCH1 IREV= 0, IDPAT= 1, MAKE= 17, KCOMP= 1, KASS= 1, IPATSYM=1,
WING_TIP_Half_Round
&PATCH2 ITP= 2, TNODES= 5, TNPS= 4, TINTS= 3, &END

&PATCH1 IREV=0, IDPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSYM=1, IPATCOP=0, &END
HORIZ STAB 0 deg 10X16
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
96.0000 0.0000 8.090
95.8703 0.0000 8.0726
95.4862 0.0000 8.0464
94.8624 0.0000 8.0056
94.0230 0.0000 7.9542
93.0001 0.0000 7.8965
91.8331 0.0000 7.8370
90.5669 0.0000 7.7806
89.2500 0.0000 7.7327
87.9331 0.0000 7.6989
86.6669 0.0000 7.6850
85.4999 0.0000 7.6952
84.4770 0.0000 7.7316
83.6376 0.0000 7.7933
83.0138 0.0000 7.8771
82.6297 0.0000 7.9775
82.5000 0.0000 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
82.6297 0.0000 8.2025
83.0138 0.0000 8.3029
83.6376 0.0000 8.3867
84.4770 0.0000 8.4484
85.4999 0.0000 8.4848
86.6669 0.0000 8.4950
87.9331 0.0000 8.4811
89.2500 0.0000 8.4473
90.5669 0.0000 8.3994
91.8331 0.0000 8.3430
93.0001 0.0000 8.2835
94.0230 0.0000 8.2258
94.8624 0.0000 8.1744
95.4862 0.0000 8.1336
95.8703 0.0000 8.1074
96.0000 0.0000 8.090
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
96.0012 0.4864 8.090
95.8725 0.4864 8.0727
95.4911 0.4864 8.0467
94.8718 0.4864 8.0062
94.0384 0.4864 7.9552
93.2291 0.4864 7.9037
91.8642 0.4864 7.8388
90.6070 0.4864 7.7828
89.2996 0.4864 7.7352
87.9921 0.4864 7.7017
86.7349 0.4864 7.6879
85.5763 0.4864 7.6980
84.5608 0.4864 7.7342
83.7273 0.4864 7.7954
83.1080 0.4864 7.8787
82.7267 0.4864 7.9783
82.5979 0.4864 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END

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82.7267 0.4864 8.2017
83.1080 0.4864 8.3013
83.7273 0.4864 8.3846
84.5608 0.4864 8.4458
85.5763 0.4864 8.4820
86.7349 0.4864 8.4921
87.9221 0.4864 8.4783
89.2596 0.4864 8.4448
90.6070 0.4864 8.3972
91.8642 0.4864 8.3412
93.2391 0.4864 8.2703
94.0384 0.4864 8.2248
94.8718 0.4864 8.1738
95.4511 0.4864 8.1333
95.8725 0.4864 8.1073
96.0012 0.4864 8.0900
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNDS=0, TNPS=0, TINTS=0, &END
96.0048 1.8979 8.0900
95.8787 1.8979 8.0731
95.5053 1.8979 8.0476
94.8990 1.8979 8.0080
94.0830 1.8979 7.9580
93.2212 1.8979 7.9091
91.9543 1.8979 7.8441
90.7234 1.8979 7.7892
89.4434 1.8979 7.7426
88.1633 1.8979 7.7098
86.9324 1.8979 7.6963
85.7980 1.8979 7.7062
84.8038 1.8979 7.7416
83.9878 1.8979 7.8015
83.3814 1.8979 7.8611
83.0080 1.8979 7.9066
82.8820 1.8979 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
83.0080 1.8979 8.1994
83.3814 1.8979 8.2969
83.9878 1.8979 8.3785
84.8038 1.8979 8.4384
85.7980 1.8979 8.4738
86.9324 1.8979 8.4837
88.1633 1.8979 8.4702
89.4434 1.8979 8.4374
90.7234 1.8979 8.3908
91.9543 1.8979 8.3359
93.2212 1.8979 8.2709
94.0830 1.8979 8.2220
94.8990 1.8979 8.1720
95.5053 1.8979 8.1324
95.8787 1.8979 8.1069
96.0048 1.8979 8.0900
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNDS=0, TNPS=0, TINTS=0, &END
96.0103 4.0964 8.0900
95.8884 4.0964 8.0736
95.5275 4.0964 8.0490
94.9413 4.0964 8.0107
94.1525 4.0964 7.9624
93.2001 4.0964 7.9086
92.0947 4.0964 7.8523
90.9048 4.0964 7.7992
89.6674 4.0964 7.7542
88.4299 4.0964 7.7224
87.2400 4.0964 7.7094
86.1434 4.0964 7.7190
85.1822 4.0964 7.7532
84.3934 4.0964 7.8111

83.8073 4.0964 7.8900
83.4463 4.0964 7.9843
83.3244 4.0964 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
83.4463 4.0964 8.1957
83.8073 4.0964 8.2900
84.3934 4.0964 8.3689
85.1822 4.0964 8.4268
86.1434 4.0964 8.4610
87.2400 4.0964 8.4706
88.4299 4.0964 8.4576
89.6674 4.0964 8.4258
90.9048 4.0964 8.3808
92.0947 4.0964 8.3277
93.2001 4.0964 8.2714
94.1525 4.0964 8.2176
94.9413 4.0964 8.1693
95.5275 4.0964 8.1310
95.8884 4.0964 8.1064
96.0103 4.0964 8.0900
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNDS=0, TNPS=0, TINTS=0, &END
96.0173 6.8666 8.0900
95.9007 6.8666 8.0743
95.5554 6.8666 8.0508
94.9947 6.8666 8.0141
94.2401 6.8666 7.9680
93.1853 6.8666 7.9088
92.2716 6.8666 7.8626
91.1334 6.8666 7.8119
89.9496 6.8666 7.7688
88.7659 6.8666 7.7384
87.6276 6.8666 7.7259
86.5786 6.8666 7.7351
85.6591 6.8666 7.7678
84.9046 6.8666 7.8233
84.1438 6.8666 7.8987
83.9986 6.8666 7.9889
83.8820 6.8666 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
83.9986 6.8666 8.1911
84.1438 6.8666 8.2813
84.9046 6.8666 8.3567
85.6591 6.8666 8.4122
86.5786 6.8666 8.4449
87.6276 6.8666 8.4541
88.7659 6.8666 8.4416
89.9496 6.8666 8.4112
91.1334 6.8666 8.3681
92.2716 6.8666 8.3174
93.1206 6.8666 8.2639
94.2401 6.8666 8.2120
94.9947 6.8666 8.1659
95.5554 6.8666 8.1292
95.9007 6.8666 8.1057
96.0173 6.8666 8.0900
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNDS=0, TNPS=0, TINTS=0, &END
96.0250 9.9375 8.0900
95.9143 9.9375 8.0751
95.5864 9.9375 8.0528
95.0538 9.9375 8.0180
94.3372 9.9375 7.9741
93.1841 9.9375 7.9099
92.4677 9.9375 7.8740
91.3867 9.9375 7.8258
90.2625 9.9375 7.7849
89.1383 9.9375 7.7561

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88.0573 9.9375 7.7442
87.0610 9.9375 7.7530
86.1878 9.9375 7.7840
85.4712 9.9375 7.8367
84.9386 9.9375 7.9083
84.6107 9.9375 7.9939
84.5000 9.9375 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
84.6107 9.9375 8.1861
84.9386 9.9375 8.2717
85.4712 9.9375 8.3433
86.1878 9.9375 8.3960
87.0610 9.9375 8.4270
88.0573 9.9375 8.4358
89.1383 9.9375 8.4239
90.2625 9.9375 8.3951
91.3867 9.9375 8.3542
92.4677 9.9375 8.3060
93.4640 9.9375 8.2552
94.3372 9.9375 8.2059
95.0538 9.9375 8.1620
95.5864 9.9375 8.1272
95.9143 9.9375 8.1049
96.0250 9.9375 8.0900
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALP=0.0, THETA=0.0, INNODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
95.9279 13.0084 8.0759
95.6173 13.0084 8.0547
95.1130 13.0084 8.0218
94.4343 13.0084 7.9802
93.1989 13.0084 7.9121
92.6638 13.0084 7.8855
91.6401 13.0084 7.8398
90.5754 13.0084 7.8011
89.5107 13.0084 7.7738
88.4869 13.0084 7.7626
87.5434 13.0084 7.7708
86.7165 13.0084 7.8002
86.0378 13.0084 7.8501
85.5334 13.0084 7.9179
85.2229 13.0084 7.9990
85.1180 13.0084 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
85.2229 13.0084 8.1810
85.5334 13.0084 8.2621
86.0378 13.0084 8.3299
86.7165 13.0084 8.3798
87.5434 13.0084 8.4092
88.4869 13.0084 8.4174
89.5107 13.0084 8.4062
90.5754 13.0084 8.3789
91.6401 13.0084 8.3402
92.6638 13.0084 8.2945
93.6073 13.0084 8.2464
94.4343 13.0084 8.1998
95.1130 13.0084 8.1582
95.6173 13.0084 8.1253
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95.6452 15.7786 8.0565
95.1664 15.7786 8.0252
94.5219 15.7786 7.9858

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91.8686 15.7786 7.8524
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88.8745 15.7786 7.7791
87.9786 15.7786 7.7869
87.1934 15.7786 7.8148
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87.9786 15.7786 8.3931
88.8745 15.7786 8.4009
89.8467 15.7786 8.3903
90.8576 15.7786 8.3643
91.8686 15.7786 8.3276
93.2260 15.7786 8.2652
93.7366 15.7786 8.2386
94.5219 15.7786 8.1942
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95.9499 17.9771 8.0772
95.6674 17.9771 8.0579
95.2087 17.9771 8.0279
94.5914 17.9771 7.9902
93.8393 17.9771 7.9477
93.2568 17.9771 7.9175
92.0500 17.9771 7.8625
91.0816 17.9771 7.8272
90.1133 17.9771 7.8024
89.1821 17.9771 7.7822
88.3240 17.9771 7.7997
87.5718 17.9771 7.8264
86.9546 17.9771 7.8718
86.4959 17.9771 7.9335
86.2134 17.9771 8.0073
86.1180 17.9771 8.0900
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86.9546 17.9771 8.3082
87.5718 17.9771 8.3536
88.3240 17.9771 8.3803
89.1821 17.9771 8.3878
90.1133 17.9771 8.3776
91.0816 17.9771 8.3528
92.0500 17.9771 8.3175
93.2568 17.9771 8.2625
93.8393 17.9771 8.2323
94.5914 17.9771 8.1898
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96.0452 17.9771 8.0900
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96.0488 19.3886 8.0900

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95.6816 19.3886 8.0588
95.2359 19.3886 8.0297
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93.9051 19.3886 7.9517
93.2810 19.3886 7.9195
92.1664 19.3886 7.8689
91.2254 19.3886 7.8347
90.2845 19.3886 7.8105
89.3796 19.3886 7.8006
88.5457 19.3886 7.8079
87.8148 19.3886 7.8339
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86.7693 19.3886 7.9379
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88.5457 19.3886 8.3721
89.3796 19.3886 8.3794
90.2845 19.3886 8.3695
91.2254 19.3886 8.3453
92.1664 19.3886 8.3111
93.2810 19.3886 8.2605
94.6361 19.3886 8.2283
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95.6816 19.3886 8.1212
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96.0488 19.3886 8.0900
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95.9582 19.8750 8.0777
95.6865 19.8750 8.0591
95.2453 19.8750 8.0303
94.6514 19.8750 7.9940
93.9278 19.8750 7.9531
93.1023 19.8750 7.9111
92.2066 19.8750 7.8711
91.2750 19.8750 7.8372
90.3434 19.8750 7.8133
89.4477 19.8750 7.8035
88.6222 19.8750 7.8107
87.8986 19.8750 7.8365
87.3047 19.8750 7.8801
86.8635 19.8750 7.9394
86.5918 19.8750 8.0104
86.5000 19.8750 8.0900
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86.8635 19.8750 8.2406
87.3047 19.8750 8.2999
87.8986 19.8750 8.3435
88.6222 19.8750 8.3693
89.4477 19.8750 8.3765
90.3434 19.8750 8.3667
91.2750 19.8750 8.3428
92.2066 19.8750 8.3089
93.1023 19.8750 8.2689
93.9278 19.8750 8.2269
94.6514 19.8750 8.1860
95.2453 19.8750 8.1497
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96.0500 19.8750 8.0900

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95.4782 0.0303 8.9075
94.6338 0.0887 8.9075
93.2811 0.1742 8.9075
91.4987 0.2765 8.9075
89.3902 0.3834 8.9075
87.0782 0.4817 8.9075
84.6969 0.5564 8.9075
82.3849 0.5917 8.9075
80.2764 0.5750 8.9075
78.4940 0.5003 8.9075
77.1413 0.3715 8.9075
76.2969 0.2001 8.9075
76.0099 0.0000 8.9075
76.2969 -0.2001 8.9075
77.1413 -0.3715 8.9075
78.4940 -0.5003 8.9075
80.2764 -0.5750 8.9075
82.3849 -0.5917 8.9075
84.6969 -0.5564 8.9075
87.0782 -0.4817 8.9075
89.3902 -0.3834 8.9075
91.4987 -0.2765 8.9075
93.2811 -0.1742 8.9075
94.6338 -0.0887 8.9075
95.4782 -0.0303 8.9075
95.7652 0.0000 8.9075
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95.4782 0.0303 8.9075
94.6338 0.0887 8.9075
93.2811 0.1742 8.9075
91.4987 0.2765 8.9075
89.3902 0.3834 8.9075
87.0782 0.4817 8.9075
84.6969 0.5564 8.9075
82.3849 0.5917 8.9075
80.2764 0.5750 8.9075
78.4940 0.5003 8.9075
77.1413 0.3715 8.9075
76.2969 0.2001 8.9075
76.0099 0.0000 8.9075
76.2969 -0.2001 8.9075
77.1413 -0.3715 8.9075
78.4940 -0.5003 8.9075
80.2764 -0.5750 8.9075
82.3849 -0.5917 8.9075
84.6969 -0.5564 8.9075
87.0782 -0.4817 8.9075
89.3902 -0.3834 8.9075
91.4987 -0.2765 8.9075
93.2811 -0.1742 8.9075
94.6338 -0.0887 8.9075
95.4782 -0.0303 8.9075
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95.9679 0.0292 10.0899
95.1538 0.0855 10.0899

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93.8498 0.1679 10.0899
92.1314 0.2665 10.0899
90.0988 0.3696 10.0899
87.8698 0.4644 10.0899
85.5742 0.5364 10.0899
83.3453 0.5704 10.0899
81.3126 0.5543 10.0899
79.5943 0.4824 10.0899
78.2902 0.3581 10.0899
77.4762 0.1929 10.0899
77.1995 0.0000 10.0899
77.4762 -0.1929 10.0899
78.2902 -0.3581 10.0899
79.5943 -0.4824 10.0899
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83.3453 -0.5704 10.0899
85.5742 -0.5364 10.0899
87.8698 -0.4644 10.0899
90.0988 -0.3696 10.0899
92.1314 -0.2665 10.0899
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96.7306 0.0275 11.9317
95.9638 0.0806 11.9317
94.7355 0.1582 11.9317
93.1170 0.2511 11.9317
91.2024 0.3481 11.9317
89.1029 0.4374 11.9317
86.9406 0.5052 11.9317
84.8411 0.5373 11.9317
82.9265 0.5221 11.9317
81.3080 0.4543 11.9317
80.0797 0.3373 11.9317
79.3129 0.1817 11.9317
79.0523 0.0000 11.9317
79.3129 -0.1817 11.9317
80.0797 -0.3373 11.9317
81.3080 -0.4543 11.9317
82.9265 -0.5221 11.9317
84.8411 -0.5373 11.9317
86.9406 -0.5052 11.9317
89.1029 -0.4374 11.9317
91.2024 -0.3481 11.9317
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97.6917 0.0251 14.2524
96.9845 0.0743 14.2524
95.8516 0.1459 14.2524
94.3589 0.2316 14.2524
92.5930 0.3211 14.2524
90.6567 0.4034 14.2524
88.6624 0.4660 14.2524
86.7260 0.4956 14.2524
84.9602 0.4815 14.2524
83.4674 0.4190 14.2524
82.3346 0.3111 14.2524
81.6274 0.1676 14.2524

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81.3870 0.0000 14.2524
81.6274 -0.1676 14.2524
82.3346 -0.3111 14.2524
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84.9602 -0.4815 14.2524
86.7260 -0.4956 14.2524
88.6624 -0.4660 14.2524
90.6567 -0.4034 14.2524
92.5930 -0.3211 14.2524
94.3589 -0.2316 14.2524
95.8516 -0.1459 14.2524
96.9845 -0.0743 14.2524
97.6917 -0.0251 14.2524
97.9321 0.0000 14.2524

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98.7571 0.0230 16.8250
98.1159 0.0674 16.8250
97.0888 0.1323 16.8250
95.7355 0.2099 16.8250
94.1345 0.2911 16.8250
92.3790 0.3657 16.8250
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88.8155 0.4493 16.8250
87.2145 0.4366 16.8250
85.8612 0.3799 16.8250
84.8341 -0.2821 16.8250
84.1929 -0.1519 16.8250
83.9750 0.0000 16.8250
84.1929 -0.1519 16.8250
84.8341 -0.2821 16.8250
85.8612 -0.3799 16.8250
87.2145 -0.4366 16.8250
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90.5710 -0.4224 16.8250
92.3790 -0.3657 16.8250
94.1345 -0.2911 16.8250
95.7355 -0.2099 16.8250
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98.1159 -0.0674 16.8250
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99.8224 0.0206 19.3976
99.2473 0.0604 19.3976
98.3260 0.1186 19.3976
97.1121 0.1883 19.3976
95.6761 0.2611 19.3976
94.1014 0.3281 19.3976
92.4796 0.3789 19.3976
90.9049 0.4030 19.3976
89.4688 0.3916 19.3976
88.2549 0.3408 19.3976
87.3336 0.2530 19.3976
86.7585 0.1363 19.3976
86.5630 0.0000 19.3976
87.3336 -0.1363 19.3976
88.2549 -0.2530 19.3976
89.4688 -0.3408 19.3976
90.9049 -0.3789 19.3976
92.4796 -0.3789 19.3976
94.1014 -0.3281 19.3976
95.6761 -0.2611 19.3976
97.1121 -0.1883 19.3976

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98.3260 -0.1186 19.3976
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99.8224 -0.0206 19.3976
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100.7835 0.0185 21.7183
100.2680 0.0542 21.7183
99.4422 0.1064 21.7183
98.3540 0.1688 21.7183
97.0667 0.2341 21.7183
95.6551 0.2941 21.7183
94.2013 0.3397 21.7183
92.7898 0.3613 21.7183
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90.4143 0.3055 21.7183
89.5885 0.2268 21.7183
89.0729 0.1221 21.7183
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98.3540 -0.1688 21.7183
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101.5463 0.0168 23.5601
101.0780 0.0492 23.5601
100.3279 0.0966 23.5601
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98.1703 0.2126 23.5601
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94.2856 0.3281 23.5601
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90.9097 0.1109 23.5601
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90.9097 -0.1109 23.5601
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100.3279 -0.0966 23.5601
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102.0360 0.0157 24.7425
101.5981 0.0460 24.7425

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100.8966 0.0903 24.7425
99.9723 0.1434 24.7425
98.8789 0.1988 24.7425
97.6799 0.2498 24.7425
96.4450 0.2885 24.7425
95.2460 0.3069 24.7425
94.1526 0.2982 24.7425
93.2283 0.2595 24.7425
92.5268 0.1926 24.7425
92.0889 0.1038 24.7425
91.9401 0.0000 24.7425
92.0889 -0.1038 24.7425
92.5268 -0.1926 24.7425
93.2283 -0.2595 24.7425
94.1526 -0.2982 24.7425
95.2460 -0.3069 24.7425
96.4450 -0.2885 24.7425
97.6799 -0.2498 24.7425
98.8789 -0.1988 24.7425
99.9723 -0.1434 24.7425
100.8966 -0.0903 24.7425
101.5981 -0.0460 24.7425
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102.1848 0.0000 24.7425
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102.2047 0.0153 25.1500
101.7773 0.0449 25.1500
101.0926 0.0882 25.1500
100.1903 0.1400 25.1500
99.1230 0.1941 25.1500
97.9527 0.2438 25.1500
96.7473 0.2816 25.1500
95.5770 0.2995 25.1500
94.5097 0.2533 25.1500
93.6074 0.2533 25.1500
92.9227 0.1880 25.1500
92.4953 0.1013 25.1500
92.3500 0.0000 25.1500
92.4953 -0.1013 25.1500
92.9227 -0.1880 25.1500
93.6074 -0.2533 25.1500
94.5097 -0.2911 25.1500
95.5770 -0.2995 25.1500
96.7473 -0.2816 25.1500
97.9527 -0.2438 25.1500
99.1230 -0.1941 25.1500
100.1903 -0.1400 25.1500
101.0926 -0.0882 25.1500
101.7773 -0.0449 25.1500
102.2047 -0.0153 25.1500
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FOG PYLON
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
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25.8000 0.0000 14.3516
25.8000 0.0000 14.5358
25.8000 0.0000 14.7201
25.8000 0.0000 14.9044
25.8000 0.0000 15.0886
25.8000 0.0000 15.2729
25.8000 0.0000 15.4572
25.8000 0.0000 15.6415

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25.8000 0.0000 15.8257
25.8000 0.0000 16.0100
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TNODES=0, TNPS=0, TINTS=0, &END
25.9300 0.5302 14.3377
25.9300 0.5302 14.3753
25.9300 0.5302 14.5556
25.9300 0.5302 14.7362
25.9300 0.5302 14.9167
25.9300 0.5302 15.0971
25.9300 0.5302 15.2776
25.9300 0.5302 15.4581
25.9300 0.5302 15.6385
25.9300 0.5302 15.8190
25.9300 0.5302 15.9995
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
26.3144 0.9601 14.4108
26.3144 0.9601 14.4384
26.3144 0.9601 14.6089
26.3144 0.9601 14.7793
26.3144 0.9601 14.9497
26.3144 0.9601 15.1201
26.3144 0.9601 15.2905
26.3144 0.9601 15.4609
26.3144 0.9601 15.6313
26.3144 0.9601 15.8017
26.3144 0.9601 15.9721
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
26.9363 1.2810 14.5052
26.9363 1.2810 14.5199
26.9363 1.2810 14.6773
26.9363 1.2810 14.8348
26.9363 1.2810 14.9922
26.9363 1.2810 15.1496
26.9363 1.2810 15.3070
26.9363 1.2810 15.4644
26.9363 1.2810 15.6219
26.9363 1.2810 15.7793
26.9363 1.2810 15.9367
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
27.7687 1.4893 14.5940
27.7687 1.4893 14.6034
27.7687 1.4893 14.7408
27.7687 1.4893 14.8859
27.7687 1.4893 15.0309
27.7687 1.4893 15.1759
27.7687 1.4893 15.3210
27.7687 1.4893 15.4660
27.7687 1.4893 15.6110
27.7687 1.4893 15.7561
27.7687 1.4893 15.9011
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
28.7750 1.5866 14.6549
28.7750 1.5866 14.6638
28.7750 1.5866 14.7837
28.7750 1.5866 14.9196
28.7750 1.5866 15.0555
28.7750 1.5866 15.1914
28.7750 1.5866 15.3273
28.7750 1.5866 15.4632
28.7750 1.5866 15.5991

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28.7750 1.5866 15.7351
28.7750 1.5866 15.8710
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
29.9113 1.5803 14.6732
29.9113 1.5803 14.6818
29.9113 1.5803 14.7940
29.9113 1.5803 14.9260
29.9113 1.5803 15.0580
29.9113 1.5803 15.1900
29.9113 1.5803 15.3220
29.9113 1.5803 15.4540
29.9113 1.5803 15.5860
29.9113 1.5803 15.7180
29.9113 1.5803 15.8500
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
31.1281 1.4826 14.6416
31.1281 1.4826 14.6504
31.1281 1.4826 14.7667
31.1281 1.4826 14.9009
31.1281 1.4826 15.0351
31.1281 1.4826 15.1694
31.1281 1.4826 15.3036
31.1281 1.4826 15.4379
31.1281 1.4826 15.5721
31.1281 1.4826 15.7063
31.1281 1.4826 15.8406
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
32.3719 1.3110 14.5598
32.3719 1.3110 14.5691
32.3719 1.3110 14.7023
32.3719 1.3110 14.8450
32.3719 1.3110 14.9877
32.3719 1.3110 15.1304
32.3719 1.3110 15.2731
32.3719 1.3110 15.4158
32.3719 1.3110 15.5585
32.3719 1.3110 15.7012
32.3719 1.3110 15.8439
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
33.5886 1.0866 14.4337
33.5886 1.0866 14.4475
33.5886 1.0866 14.6044
33.5886 1.0866 14.7614
33.5886 1.0866 14.9184
33.5886 1.0866 15.0754
33.5886 1.0866 15.2324
33.5886 1.0866 15.3894
33.5886 1.0866 15.5464
33.5886 1.0866 15.7034
33.5886 1.0866 15.8604
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
34.7250 0.8337 14.2747
34.7250 0.8337 14.3074
34.7250 0.8337 14.4831
34.7250 0.8337 14.6589
34.7250 0.8337 14.8347
34.7250 0.8337 15.0105
34.7250 0.8337 15.1863
34.7250 0.8337 15.3621
34.7250 0.8337 15.5379

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34.7250 0.8337 15.7137
34.7250 0.8337 15.8895
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
35.7313 0.5784 14.0992
35.7313 0.5784 14.1537
35.7313 0.5784 14.3510
35.7313 0.5784 14.5484
35.7313 0.5784 14.7457
35.7313 0.5784 14.9430
35.7313 0.5784 15.1403
35.7313 0.5784 15.3377
35.7313 0.5784 15.5350
35.7313 0.5784 15.7323
35.7313 0.5784 15.9296
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
36.5637 0.3462 13.9276
36.5637 0.3462 14.0041
36.5637 0.3462 14.2235
36.5637 0.3462 14.4428
36.5637 0.3462 14.6622
36.5637 0.3462 14.8815
36.5637 0.3462 15.1009
36.5637 0.3462 15.3203
36.5637 0.3462 15.5396
36.5637 0.3462 15.7590
36.5637 0.3462 15.9783
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
37.1856 0.1609 13.7823
37.1856 0.1609 13.8781
37.1856 0.1609 14.1173
37.1856 0.1609 14.3565
37.1856 0.1609 14.5957
37.1856 0.1609 14.8349
37.1856 0.1609 15.0741
37.1856 0.1609 15.3134
37.1856 0.1609 15.5526
37.1856 0.1609 15.7918
37.1856 0.1609 16.0310
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
37.5700 0.0413 13.6845
37.5700 0.0413 13.7951
37.5700 0.0413 14.0488
37.5700 0.0413 14.3025
37.5700 0.0413 14.5562
37.5700 0.0413 14.8099
37.5700 0.0413 15.0636
37.5700 0.0413 15.3173
37.5700 0.0413 15.5710
37.5700 0.0413 15.8247
37.5700 0.0413 16.0784
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
37.7000 0.0000 13.6500
37.7000 0.0000 13.7663
37.7000 0.0000 14.0256
37.7000 0.0000 14.2849
37.7000 0.0000 14.5442
37.7000 0.0000 14.8035
37.7000 0.0000 15.0628
37.7000 0.0000 15.3221
37.7000 0.0000 15.5814

37.7000 0.0000 15.8407
37.7000 0.0000 16.1000
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&PATCH1 IREV=0, IDPAT=2, MAKE=0, KCOMP=1, KASS=1, IPATSYM=1, IPATCOP=0, &END
FOG ENGINE POD
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
16.5000 0.0000 20.4000
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
16.7895 0.0000 19.7036
16.7895 0.1802 19.7381
16.7895 0.3338 19.8311
16.7895 0.4530 19.9692
16.7895 0.5342 20.1491
16.7895 0.5642 20.3542
16.7895 0.5363 20.5590
16.7895 0.4556 20.7374
16.7895 0.3349 20.8747
16.7895 0.1800 20.9661
16.7895 0.0000 20.9995
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
17.6455 0.0000 18.9621
17.6455 0.4134 19.0316
17.6455 0.7696 19.2229
17.6455 1.0398 19.5042
17.6455 1.2183 19.8707
17.6455 1.2728 20.2955
17.6455 1.1966 20.7383
17.6455 1.0093 21.1240
17.6455 0.7418 21.4169
17.6455 0.3972 21.6150
17.6455 0.0000 21.6870
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
19.0305 0.0000 17.6702
19.0305 0.7979 17.7380
19.0305 1.3113 17.9554
19.0305 1.6163 18.3439
19.0305 1.7872 18.9932
19.0305 1.8434 19.9738
19.0305 1.7865 20.8477
19.0305 1.5906 21.4633
19.0305 1.2554 21.8603
19.0305 0.7367 22.0950
19.0305 0.0000 22.1718
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
20.8840 0.0000 16.8347
20.8840 1.3042 16.8570
20.8840 1.8746 16.9602
20.8840 2.0812 17.2524
20.8840 2.1525 18.0117

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20.8840 2.1689 19.5462
20.8840 2.1572 21.0957
20.8840 2.0882 21.8715
20.8840 1.8780 22.1653
20.8840 1.1111 22.2650
20.8840 0.0000 22.2869
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
23.1250 0.0000 16.3511
23.1250 1.4033 16.3708
23.1250 2.0127 16.4691
23.1250 2.2204 16.7715
23.1250 2.2862 17.5999
23.1250 2.2999 19.2276
23.1250 2.2915 20.8939
23.1250 2.2329 21.7791
23.1250 2.0307 22.0844
23.1250 1.4246 22.1766
23.1250 0.0000 22.1945
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
25.6555 0.0000 16.0481
25.6555 1.4141 16.0679
25.6555 2.0188 16.1668
25.6555 2.2226 16.4703
25.6555 2.2870 17.3089
25.6555 2.2999 18.9446
25.6555 2.2912 20.6132
25.6555 2.2327 21.5039
25.6555 2.0316 21.8124
25.6555 1.4305 21.9057
25.6555 0.0000 21.9240
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
28.3650 0.0000 15.8494
28.3650 1.4144 15.8682
28.3650 2.0199 15.9622
28.3650 2.2237 16.2532
28.3650 2.2875 17.0611
28.3650 2.3000 18.6632
28.3650 2.2900 20.2862
28.3650 2.2287 21.1215
28.3650 2.0240 21.4109
28.3650 1.4190 21.4999
28.3650 0.0000 21.5175
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
31.1350 0.0000 15.7474
31.1350 1.3961 15.7637
31.1350 2.0103 15.8456
31.1350 2.2203 16.1006
31.1350 2.2865 16.8111
31.1350 2.3000 18.3044
31.1350 2.2888 19.8200
31.1350 2.2242 20.5497
31.1350 2.0130 20.8000
31.1350 1.3979 20.8773
31.1350 0.0000 20.8925
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
33.8445 0.0000 15.8093
33.8445 1.3627 15.8218
33.8445 1.9940 15.8864
33.8445 2.2152 16.0907
33.8445 2.2852 16.6649

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33.8445 2.3000 17.9747
33.8445 2.2868 19.3038
33.8445 2.2166 19.8875
33.8445 1.9942 20.0845
33.8445 1.3615 20.1457
33.8445 0.0000 20.1575
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
36.3750 0.0000 15.9892
36.3750 1.3053 15.9975
36.3750 1.9691 16.0428
36.3750 2.2080 16.1903
36.3750 2.2835 16.6129
36.3750 2.3000 17.6647
36.3750 2.2844 18.7297
36.3750 2.2062 19.1542
36.3750 1.9627 19.2941
36.3750 1.2912 19.3166
36.3750 0.0000 19.3443
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
38.6160 0.0000 16.2138
38.6160 1.1972 16.2181
38.6160 1.9280 16.2456
38.6160 2.1972 16.3400
38.6160 2.2813 16.6192
38.6160 2.3000 17.3609
38.6160 2.2827 18.1111
38.6160 2.1968 18.4163
38.6160 1.9293 18.5068
38.6160 1.2029 18.5335
38.6160 0.0000 18.5378
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
40.4695 0.0000 16.4386
40.4695 1.0541 16.4404
40.4695 1.8638 16.4540
40.4695 2.1814 16.5048
40.4695 2.2786 16.6646
40.4695 2.3000 17.1216
40.4695 2.2796 17.6011
40.4695 2.1790 17.7620
40.4695 1.8677 17.8097
40.4695 1.0610 17.8229
40.4695 0.0000 17.8247
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
41.8545 0.0000 16.6286
41.8545 0.8776 16.6291
41.8545 1.7102 16.6332
41.8545 2.1282 16.6520
41.8545 2.2589 16.7231
41.8545 2.2846 16.9507
41.8545 2.2559 17.1850
41.8545 2.1229 17.2486
41.8545 1.7061 17.2659
41.8545 0.8776 17.2699
41.8545 0.0000 17.2703
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
42.7105 0.0000 16.7554
42.7105 0.6609 16.7566
42.7105 1.2924 16.7619
42.7105 1.7606 16.7743
42.7105 2.0332 16.7974

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42.7105 2.1274 16.8434
42.7105 2.0340 16.8795
42.7105 1.7674 16.9014
42.7105 1.3047 16.9135
42.7105 0.6710 16.9187
42.7105 0.0000 16.9198
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODE=5, TNPS=0, TINTS=0, &END
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
43.0000 0.0000 16.8000
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

&PATCH1 IREV=0, IDPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSYM=0, IPATCOP=0, &END
RIGHT ALL - 5 DEG UP
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
44.5896 31.5000 11.5308
44.3717 31.5000 11.4932
43.7277 31.5000 11.4770
42.6855 31.5000 11.4565
41.2909 31.5000 11.4290
39.6047 31.5000 11.4012
37.7006 31.5000 11.3871
35.6619 31.5000 11.3790
33.5777 31.5000 11.3991
31.5390 31.5000 11.4614
29.6349 31.5000 11.5647
27.9487 31.5000 11.7283
26.5541 31.5000 11.9690
25.5119 31.5000 12.2862
24.8679 31.5000 12.6691
24.6500 31.5000 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END

24.8679 31.5000 13.5517
25.5119 31.5000 13.9485
26.5541 31.5000 14.2646
27.9487 31.5000 14.4706
29.6349 31.5000 14.5367
31.5390 31.5000 14.4449
33.5777 31.5000 14.2088
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44.4810 32.0261 11.7835
43.8389 32.0261 11.7108
42.7994 32.0261 11.5989
41.1500 32.0261 11.4266
39.6500 32.0261 11.4037
37.7402 32.0261 11.3873

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35.6953 32.0261 11.3790
33.6047 32.0261 11.3986
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24.8685 32.0261 12.6685
24.6500 32.0261 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END

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27.9587 32.0261 14.4714
29.6500 32.0261 14.5366
31.5598 32.0261 14.4431
33.6047 32.0261 14.2049
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37.7402 32.0261 13.4385
39.6500 32.0261 12.9867
41.1112 32.0261 12.5589
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39.6500 33.5531 11.4037
37.7402 33.5531 11.3873
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33.6047 33.5531 11.3986
31.5598 33.5531 11.4606
29.6500 33.5531 11.5637
27.9587 33.5531 11.7270
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24.6500 33.5531 13.1000
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26.5598 33.5531 14.2658
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29.6500 33.5531 14.5366
31.5598 33.5531 14.4431
33.6047 33.5531 14.2049
35.6953 33.5531 13.8565
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43.8389 35.9313 11.7108
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41.1500 35.9313 11.4266
39.6500 35.9313 11.4037
37.7402 35.9313 11.3873

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29.6500 48.5687 14.5366
31.5598 48.5687 14.4431
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35.6953 48.5687 13.8565
37.7402 48.5687 13.4385
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41.3112 48.5687 12.5899
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27.9587 50.9469 14.4714
29.6500 50.9469 14.5366
31.5598 50.9469 14.4431
33.6047 50.9469 14.2049
35.6953 50.9469 13.8565
37.7402 50.9469 13.4385
39.6500 50.9469 12.9867
41.3112 50.9469 12.5899
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44.4810 52.4739 11.7835
43.8389 52.4739 11.7108
42.7994 52.4739 11.5989
41.1500 52.4739 11.4266
39.6500 52.4739 11.4037
37.7402 52.4739 11.3873
35.6953 52.4739 11.3790
33.6047 52.4739 11.3986
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27.9587 52.4739 11.7270
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29.6500 52.4739 14.5366
31.5598 52.4739 14.4431
33.6047 52.4739 14.2049
35.6953 52.4739 13.8565
37.7402 52.4739 13.4385
39.6500 52.4739 12.9867
41.3112 52.4739 12.5899
42.7396 52.4739 12.2831
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44.4810 53.0000 11.7835
43.8389 53.0000 11.7108
42.7994 53.0000 11.5989
41.1500 53.0000 11.4266
39.6500 53.0000 11.4037
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33.6047 53.0000 11.3986
31.5598 53.0000 11.4606
29.6500 53.0000 11.5637
27.9587 53.0000 11.7270
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24.6500 53.0000 13.1000
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29.6349 53.0000 14.5367
31.5390 53.0000 14.4449
33.5777 53.0000 14.2088
35.6619 53.0000 13.8627
37.7006 53.0000 13.4473
39.6047 53.0000 12.9980
41.2909 53.0000 12.5573
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44.3717 -31.5000 11.4932
43.7277 -31.5000 11.4770

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33.6047 52.4739 11.3986
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29.6500 52.4739 11.5637
27.9587 52.4739 11.7270
26.5598 52.4739 11.9677
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24.8685 52.4739 12.6685
24.6500 52.4739 13.1000
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29.6500 52.4739 14.5366
31.5598 52.4739 14.4431
33.6047 52.4739 14.2049
35.6953 52.4739 13.8565
37.7402 52.4739 13.4385
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41.3112 52.4739 12.5899
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41.2909 53.0000 11.4290
39.6047 53.0000 11.4032
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31.5390 53.0000 11.4614
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27.9487 53.0000 11.7283
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31.5390 -31.5000 14.4449
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37.7006 -31.5000 13.4473
39.6047 -31.5000 12.9980
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43.7120 -32.0261 11.2514
42.6688 -32.0261 11.3217
41.1500 -32.0261 11.4266
39.6500 -32.0261 11.4037
37.7402 -32.0261 11.3873
35.6953 -32.0261 11.3790
33.6047 -32.0261 11.3986
31.5598 -32.0261 11.4606
29.6500 -32.0261 11.5637
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27.9587 -32.0261 14.4714
29.6500 -32.0261 14.5366
31.5598 -32.0261 14.4431
33.6047 -32.0261 14.2049
35.6953 -32.0261 13.8565
37.7402 -32.0261 13.4385
39.6500 -32.0261 12.9867
41.3699 -32.0261 12.5256
42.7287 -32.0261 12.0059
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44.3674 -32.0261 11.3305
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44.3570 -33.5531 11.2115
43.7120 -33.5531 11.2514

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39.6500 -33.5531 11.4037
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35.6953 -33.5531 11.3790
33.6047 -33.5531 11.3986
31.5598 -33.5531 11.4606
29.6500 -33.5531 11.5637
27.9587 -33.5531 11.7270
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24.8685 -33.5531 12.6685
24.6500 -33.5531 13.1000
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27.9587 -33.5531 14.4714
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33.6047 -33.5531 14.2049
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37.7402 -33.5531 13.4385
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41.3699 -33.5531 12.5256
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24.6500 -35.9313 13.1000
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27.9587 -35.9313 14.4714
29.6500 -35.9313 14.5366
31.5598 -35.9313 14.4431
33.6047 -35.9313 14.2049
35.6953 -35.9313 13.8565
37.7402 -35.9313 13.4385
39.6500 -35.9313 12.9867
41.3699 -35.9313 12.5256
42.7287 -35.9313 12.0059
43.7419 -35.9313 11.5935
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44.3570 -38.9281 11.2115
43.7120 -38.9281 11.2514

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42.6688 38.9281 11.3217
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29.6500 -38.9281 11.5637
27.9587 -38.9281 11.7270
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24.8685 -38.9281 12.6685
24.6500 -38.9281 13.1000
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26.5598 -38.9281 14.2658
27.9587 -38.9281 14.4714
29.6500 -38.9281 14.5366
31.5598 -38.9281 14.4431
33.6047 -38.9281 14.2049
35.6953 -38.9281 13.8565
37.7402 -38.9281 13.4385
39.6500 -38.9281 12.9867
41.3699 -38.9281 12.5256
42.7287 -38.9281 12.0059
43.7419 -38.9281 11.5935
44.3674 -38.9281 11.3305
44.518 -38.9281 11.232
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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39.6500 -42.2500 11.4037
37.7402 -42.2500 11.3873
35.6953 -42.2500 11.3790
33.6047 -42.2500 11.3986
31.5598 -42.2500 11.3986
29.6500 -42.2500 11.5637
27.9587 -42.2500 11.7270
26.5598 -42.2500 11.9677
25.5145 -42.2500 12.2851
24.8685 -42.2500 12.6685
24.6500 -42.2500 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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27.9587 -42.2500 14.4714
29.6500 -42.2500 14.5366
31.5598 -42.2500 14.4431
33.6047 -42.2500 14.2049
35.6953 -42.2500 13.8565
37.7402 -42.2500 13.4385
39.6500 -42.2500 12.9867
41.3699 -42.2500 12.5256
42.7287 -42.2500 12.0059
43.7419 -42.2500 11.5935
44.3674 -42.2500 11.3305
44.518 -42.2500 11.232
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44.3570 -45.5719 11.2115
43.7120 -45.5719 11.2514

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39.6500 -45.5719 11.4037
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35.6953 -45.5719 11.3790
33.6047 -45.5719 11.3986
31.5598 -45.5719 11.4606
29.6500 -45.5719 11.5637
27.9587 -45.5719 11.7270
26.5598 -45.5719 11.9677
25.5145 -45.5719 12.2851
24.8685 -45.5719 12.6685
24.6500 -45.5719 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 -45.5719 13.5524
25.5145 -45.5719 13.9496
26.5598 -45.5719 14.2658
27.9587 -45.5719 14.4714
29.6500 -45.5719 14.5366
31.5598 -45.5719 14.4431
33.6047 -45.5719 14.2049
35.6953 -45.5719 13.8565
37.7402 -45.5719 13.4385
39.6500 -45.5719 12.9867
41.3699 -45.5719 12.5256
42.7287 -45.5719 12.0059
43.7419 -45.5719 11.5935
44.3674 -45.5719 11.3305
44.518 -45.5719 11.232
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
44.518 -48.5687 11.232
44.3570 -48.5687 11.2115
43.7120 -48.5687 11.2514
42.6688 -48.5687 11.3217
41.1500 -48.5687 11.4266
39.6500 -48.5687 11.4037
37.7402 -48.5687 11.3873
35.6953 -48.5687 11.3790
33.6047 -48.5687 11.3986
31.5598 -48.5687 11.3986
29.6500 -48.5687 11.5637
27.9587 -48.5687 11.7270
26.5598 -48.5687 11.9677
25.5145 -48.5687 12.2851
24.8685 -48.5687 12.6685
24.6500 -48.5687 13.1000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
24.8685 -48.5687 13.5524
25.5145 -48.5687 13.9496
26.5598 -48.5687 14.2658
27.9587 -48.5687 14.4714
29.6500 -48.5687 14.5366
31.5598 -48.5687 14.4431
33.6047 -48.5687 14.2049
35.6953 -48.5687 13.8565
37.7402 -48.5687 13.4385
39.6500 -48.5687 12.9867
41.3699 -48.5687 12.5256
42.7287 -48.5687 12.0059
43.7419 -48.5687 11.5935
44.3674 -48.5687 11.3305
44.518 -48.5687 11.232
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
44.518 -50.9469 11.232
44.3570 -50.9469 11.2115
43.7120 -50.9469 11.2514

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&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODS=0, TNPS=0, TINTS=0, &END
95.9907 0.4864 7.851
95.8609 0.4864 7.8432
95.4787 0.4864 7.8506
94.8583 0.4864 7.8642
94.0236 0.4864 7.8861
93.2391 0.4864 7.9097
91.8642 0.4864 7.8388
90.6070 0.4864 7.7828
89.2996 0.4864 7.7352
87.9921 0.4864 7.7017
86.7349 0.4864 7.6879
85.5763 0.4864 7.6980
84.5608 0.4864 7.7342
83.7273 0.4864 7.7954
83.1080 0.4864 7.8787
82.7267 0.4864 7.9783
82.5979 0.4864 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
82.7267 0.4864 8.2017
83.1080 0.4864 8.3013
83.7273 0.4864 8.3846
84.5608 0.4864 8.4858
85.5763 0.4864 8.4820
86.7349 0.4864 8.4921
87.9921 0.4864 8.4783
89.2996 0.4864 8.4448
90.6070 0.4864 8.3972
91.8642 0.4864 8.3412
93.2391 0.4864 8.2703
94.0471 0.4864 8.1546
94.8729 0.4864 8.0312
95.4863 0.4864 7.9369
95.8639 0.4864 7.8777
95.9907 0.4864 7.851
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
95.9941 1.8979 7.847
95.8671 1.8979 7.8415
95.4529 1.8979 7.8487
94.8854 1.8979 7.8621
94.0682 1.8979 7.8834
93.2212 1.8979 7.9091
91.9543 1.8979 7.8441
90.7234 1.8979 7.7892
89.4434 1.8979 7.7426
88.1633 1.8979 7.7098
86.9324 1.8979 7.6963
85.7980 1.8979 7.7062
84.8038 1.8979 7.7416
83.9878 1.8979 7.8015
83.3814 1.8979 7.8831
83.0080 1.8979 7.9806
82.8820 1.8979 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
83.0080 1.8979 8.1994
83.3814 1.8979 8.2969
83.9878 1.8979 8.3785
84.8038 1.8979 8.4384
85.7980 1.8979 8.4738
86.9324 1.8979 8.4837
88.1633 1.8979 8.4702
89.4434 1.8979 8.4374
90.7234 1.8979 8.3908
91.9543 1.8979 8.3359
93.2212 1.8979 8.2709
94.0312 1.8979 8.1464

94.8997 1.8979 8.0255
95.5003 1.8979 7.9132
95.8701 1.8979 7.8753
95.9941 1.8979 7.847
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODS=0, TNPS=0, TINTS=0, &END
95.9996 4.0964 7.845
95.8768 4.0964 7.8194
95.5150 4.0964 7.8463
94.3278 4.0964 7.8592
94.1378 4.0964 7.8799
93.2001 4.0964 7.9086
92.0947 4.0964 7.8523
90.9048 4.0964 7.7992
89.6674 4.0964 7.7542
88.4299 4.0964 7.7224
87.2400 4.0964 7.7094
86.1434 4.0964 7.7190
85.1822 4.0964 7.7532
84.3934 4.0964 7.8111
83.8073 4.0964 7.8900
83.4463 4.0964 7.9843
83.3244 4.0964 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
83.4463 4.0964 8.1957
83.8073 4.0964 8.2900
84.3934 4.0964 8.3689
85.1822 4.0964 8.4268
86.1434 4.0964 8.4610
87.2400 4.0964 8.4706
88.4299 4.0964 8.4576
89.6674 4.0964 8.4258
90.9048 4.0964 8.3808
92.0947 4.0964 8.3277
93.2001 4.0964 8.2714
94.1600 4.0964 8.1341
94.9416 4.0964 8.0172
95.5222 4.0964 7.9280
95.8756 4.0964 7.8720
95.9996 4.0964 7.845
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INNODE=4,
TNODS=0, TNPS=0, TINTS=0, &END
96.004 6.8667 7.843
95.8870 6.8667 7.8378
95.5410 6.8667 7.8445
94.9792 6.8667 7.8568
94.2234 6.8667 7.8766
93.1853 6.8666 7.9088
92.2716 6.8666 7.8626
91.1334 6.8666 7.8119
89.9496 6.8666 7.7688
88.7659 6.8666 7.7384
87.6276 6.8666 7.7259
86.5786 6.8666 7.7351
85.6591 6.8666 7.7678
84.9046 6.8666 7.8233
84.3438 6.8666 7.8987
83.9986 6.8666 7.9889
83.8820 6.8666 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
83.9986 6.8666 8.1911
84.3438 6.8666 8.2813
84.9046 6.8666 8.3567
85.6591 6.8666 8.4122
86.5786 6.8666 8.4449
87.6276 6.8666 8.4541
88.7659 6.8666 8.4416
89.9496 6.8666 8.4112

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91.1334 6.8666 8.3681
92.2716 6.8666 8.3174
93.3333 6.8666 8.2516
94.2447 6.8666 8.1197
94.9924 6.8666 8.0080
95.5478 6.8667 7.9226
95.8897 6.8667 7.8690
96.0004 6.8667 7.843
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
96.0126 9.9375 7.843
95.9010 9.9375 7.8373
95.5724 9.9375 7.8436
95.0389 9.9375 7.8553
94.3211 9.9375 7.8741
93.1841 9.9375 7.9099
92.4677 9.9375 7.8740
91.3867 9.9375 7.8258
90.2625 9.9375 7.7849
89.1383 9.9375 7.7561
88.0573 9.9375 7.7442
87.0610 9.9375 7.7530
86.1878 9.9375 7.7840
85.4712 9.9375 7.8367
84.9386 9.9375 7.9083
84.6107 9.9375 7.9539
84.5000 9.9375 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
84.6107 9.9375 8.1861
84.9386 9.9375 8.2717
85.4712 9.9375 8.3433
86.1878 9.9375 8.3960
87.0610 9.9375 8.4270
88.0573 9.9375 8.4358
89.1383 9.9375 8.4239
90.2625 9.9375 8.3951
91.3867 9.9375 8.3542
92.4677 9.9375 8.3060
93.4757 9.9375 8.2302
94.3414 9.9375 8.1050
95.0514 9.9375 7.9989
95.5789 9.9375 7.9178
95.9036 9.9375 7.8669
96.0126 9.9375 7.843
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
96.0208 13.0084 7.843
95.9151 13.0084 7.8382
95.6039 13.0084 7.8441
95.0986 13.0084 7.8553
94.4189 13.0084 7.8730
93.1989 13.0084 7.9121
92.6638 13.0084 7.8855
91.6401 13.0084 7.8398
90.5754 13.0084 7.8011
89.5107 13.0084 7.7738
88.4869 13.0084 7.7626
87.5434 13.0084 7.7708
86.7165 13.0084 7.8002
86.0378 13.0084 7.8501
85.5334 13.0084 7.9179
85.2229 13.0084 7.9990
85.1180 13.0084 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
85.2229 13.0084 8.1810
85.5334 13.0084 8.2621
86.0378 13.0084 8.3299
86.7165 13.0084 8.3798

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87.5434 13.0084 8.4092
88.4869 13.0084 8.4174
89.5107 13.0084 8.4062
90.5754 13.0084 8.3789
91.6401 13.0084 8.3402
92.6638 13.0084 8.2945
93.6182 13.0083 8.2103
94.4380 13.0083 8.0917
95.1105 13.0084 7.9912
95.6100 13.0084 7.9144
95.9175 13.0084 7.8662
96.0208 13.0084 7.843
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
96.029 15.7786 7.844
95.9286 15.7786 7.8401
95.6331 15.7786 7.8458
95.1533 15.7786 7.8563
94.5079 15.7786 7.8732
93.7217 15.7786 7.8975
93.2260 15.7786 7.9148
91.8686 15.7786 7.8524
90.8576 15.7786 7.8157
89.8467 15.7786 7.7897
88.8745 15.7786 7.7791
87.9786 15.7786 7.7869
87.1934 15.7786 7.8148
86.5489 15.7786 7.8622
86.0700 15.7786 7.9266
85.7751 15.7786 8.0036
85.6756 15.7786 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
85.7751 15.7786 8.1764
86.0700 15.7786 8.2534
86.5489 15.7786 8.3178
87.1934 15.7786 8.3652
87.9786 15.7786 8.3931
88.8745 15.7786 8.4009
89.8467 15.7786 8.3903
90.8576 15.7786 8.3643
91.8686 15.7786 8.3276
93.2260 15.7786 8.2652
93.7476 15.7786 8.1935
94.5261 15.7786 8.0809
95.1646 15.7786 7.9854
95.6389 15.7786 7.9125
95.9310 15.7786 7.8668
96.029 15.7786 7.844
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODE=0, TNPS=0, TINTS=0, &END
96.0347 17.9771 7.847
95.9385 17.9771 7.8425
95.6554 17.9771 7.8480
95.1959 17.9771 7.8581
94.5776 17.9771 7.8742
93.8246 17.9771 7.8975
93.2568 17.9771 7.9175
92.0500 17.9771 7.8625
91.0816 17.9771 7.8272
90.1133 17.9771 7.8024
89.1821 17.9771 7.7922
88.3240 17.9771 7.7997
87.5718 17.9771 7.8264
86.9546 17.9771 7.8718
86.4959 17.9771 7.9335
86.2134 17.9771 8.0073
86.1180 17.9771 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END

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86.2134 17.9771 8.1727
86.4959 17.9771 8.2465
86.9546 17.9771 8.3082
87.5718 17.9771 8.3536
88.3240 17.9771 8.3803
89.1821 17.9771 8.3878
90.1133 17.9771 8.3776
91.0816 17.9771 8.3528
92.0500 17.9771 8.3175
93.2568 17.9771 8.2625
94.8494 17.9771 8.1810
95.5950 17.9771 8.0731
96.2067 17.9771 7.9817
97.6610 17.9771 7.9119
98.9407 17.9771 7.8681
99.0347 17.9771 7.847
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
96.0382 19.3886 7.848
95.9448 19.3886 7.8444
95.6698 19.3887 7.8497
95.2232 19.3887 7.8595
94.6224 19.3887 7.8753
91.8907 19.3887 7.8979
91.2810 19.3886 7.9195
92.1664 19.3886 7.8689
91.2254 19.3886 7.8347
90.2845 19.3886 7.8105
88.3796 19.3886 7.8006
88.5457 19.3886 7.8079
87.8148 19.3886 7.8339
87.2150 19.3886 7.8780
86.7693 19.3886 7.9379
86.4948 19.3886 8.0096
86.4021 19.3886 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
86.4948 19.3886 8.1704
86.7693 19.3886 8.2421
87.2150 19.3886 8.3020
87.8148 19.3886 8.3461
88.5457 19.3886 8.3721
89.3796 19.3886 8.3794
90.2845 19.3886 8.3695
91.2254 19.3886 8.3453
92.1664 19.3886 8.3111
93.2810 19.3886 8.2605
94.6394 19.3886 8.1733
95.2337 19.3886 7.9797
95.6752 19.3886 7.9118
95.9470 19.3886 7.8693
96.0382 19.3886 7.848
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=3, TNPS=0, TINTS=0, &END
96.0395 19.8750 7.849
95.9470 19.8750 7.8452
95.6747 19.8750 7.8504
95.2326 19.8750 7.8601
94.6379 19.8750 7.8757
93.9135 19.8750 7.8980
93.2900 19.8750 7.9202
92.2066 19.8750 7.9711
91.2750 19.8750 7.8372
90.3434 19.8750 7.8133
89.4477 19.8750 7.8035
88.6222 19.8750 7.8107
87.8986 19.8750 7.8365
87.3047 19.8750 7.8801

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86.8635 19.8750 7.9394
86.5948 19.8750 8.0104
86.5000 19.8750 8.0900
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
86.5918 19.8750 8.1696
86.8635 19.8750 8.2406
87.3047 19.8750 8.2999
87.8986 19.8750 8.3435
88.6222 19.8750 8.3693
89.4477 19.8750 8.3765
90.3434 19.8750 8.3667
91.2750 19.8750 8.3428
92.2066 19.8750 8.3089
93.2900 19.8750 8.2598
93.9374 19.8750 8.1708
94.6546 19.8750 8.0670
95.2430 19.8750 7.9791
95.6801 19.8750 7.9119
95.9492 19.8750 7.8697
96.0395 19.8750 7.849
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&PATCH1 IREV=0, IPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSYM=0, IPATCOP=0, &END
RUDDER +5 DEG (TEL) 10X12
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
97.4877 -0.413 10.4049
97.1510 -0.3501 10.4038
96.1610 -0.2008 10.4006
94.5854 0.0287 10.3958
92.5000 0.3161 10.4000
90.0882 0.4315 10.4000
87.5000 0.5294 10.4000
84.9118 0.5900 10.4000
82.5000 0.5942 10.4000
80.4289 0.5310 10.4000
78.8397 0.4015 10.4000
77.8407 0.2183 10.4000
77.5000 0.0000 10.4000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
77.8407 -0.2183 10.4000
78.8397 -0.4015 10.4000
80.4289 -0.5310 10.4000
82.5000 -0.5942 10.4000
84.9118 -0.5900 10.4000
87.5000 -0.5294 10.4000
90.0882 -0.4315 10.4000
92.4786 -0.3151 10.4070
94.5521 -0.3721 10.4067
96.1439 -0.4057 10.4062
97.1451 -0.4218 10.4058
97.4877 -0.413 10.4056
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
97.6057 -0.4180 10.7661
97.2733 -0.3558 10.7650
96.2954 -0.2083 10.7618
94.7391 0.0183 10.7570
92.5590 0.3185 10.7610
90.2976 0.4262 10.7610
87.7410 0.5229 10.7610
85.1845 0.5828 10.7610
82.6022 0.5869 10.7610
80.7565 0.5245 10.7610
79.1868 0.3966 10.7610
78.2000 0.2157 10.7610
77.8634 0.0000 10.7610
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
78.2000 -0.2157 10.7610

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79.1868 -0.3966 10.7610
80.7565 -0.5245 10.7610
82.8022 -0.5869 10.7610
85.1845 -0.5829 10.7610
87.7410 -0.5229 10.7610
90.2976 -0.4262 10.7610
92.6581 -0.3212 10.7682
94.7062 -0.3775 10.7679
96.2786 -0.4108 10.7674
97.2674 -0.4267 10.7669
97.6057 -0.4180 10.7668
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
97.9488 -0.432 11.8141
97.6283 -0.3710 11.8131
96.6855 -0.2288 11.8100
95.1852 -0.0103 11.8054
92.7472 -0.3243 11.8085
90.9052 -0.4109 11.8085
88.4406 -0.5041 11.8085
85.9760 -0.5618 11.8085
83.6793 -0.5658 11.8085
81.7071 -0.5056 11.8085
80.1938 -0.3823 11.8085
79.2425 -0.2079 11.8085
78.9180 -0.0000 11.8085
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
79.2425 -0.2079 11.8085
80.1938 -0.3823 11.8085
81.7071 -0.5056 11.8085
83.6793 -0.5658 11.8085
85.9760 -0.5618 11.8085
88.4406 -0.5041 11.8085
90.9052 -0.4109 11.8085
92.7472 -0.3243 11.8085
95.1852 -0.0103 11.8054
96.6855 -0.2288 11.8100
97.6283 -0.3710 11.8131
97.9488 -0.432 11.8141
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
98.4834 -0.448 13.4464
98.1815 -0.3905 13.4454
97.2935 -0.2565 13.4426
95.8802 -0.0507 13.4382
93.0906 -0.3301 13.4401
91.8516 -0.3871 13.4401
89.5302 -0.4748 13.4401
87.2087 -0.5292 13.4401
85.0454 -0.5330 13.4401
83.1878 -0.4763 13.4401
81.7624 -0.3601 13.4401
80.8663 -0.1958 13.4401
80.5607 -0.0000 13.4401
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
80.8663 -0.1958 13.4401
81.7624 -0.3601 13.4401
83.1878 -0.4763 13.4401
85.0454 -0.5330 13.4401
87.2087 -0.5292 13.4401
89.5302 -0.4748 13.4401
91.8516 -0.3871 13.4401
93.0906 -0.3591 13.4483
95.8504 -0.4102 13.4480
97.2782 -0.4404 13.4476
98.1762 -0.4548 13.4472
98.4834 -0.448 13.4470
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
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99.1565 -0.460 15.5033
98.8781 -0.4077 15.5024
98.0591 -0.2842 15.4998
96.7556 -0.0944 15.4958
95.0561 -0.1422 15.4908
93.6103 -0.1318 15.4960
90.9031 -0.4380 15.4960
88.7620 -0.4881 15.4960
86.7668 -0.4916 15.4960
85.0535 -0.4393 15.4960
83.7389 -0.3321 15.4960
82.9124 -0.1806 15.4960
82.6305 -0.0000 15.4960
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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85.0535 -0.4393 15.4960
86.7668 -0.4916 15.4960
88.7620 -0.4881 15.4960
90.9031 -0.4380 15.4960
93.6103 -0.1318 15.4960
95.0128 -0.3788 15.5051
96.7281 -0.4259 15.5048
98.0450 -0.4538 15.5044
98.8731 -0.4671 15.5040
99.1565 -0.460 15.5039
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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99.6562 -0.4178 17.7807
98.9136 -0.3058 17.7783
97.7319 -0.1337 17.7746
96.1911 -0.0808 17.7702
94.3000 -0.3265 17.7750
92.4250 -0.3971 17.7750
90.4839 -0.4425 17.7750
88.6750 -0.4456 17.7750
87.1217 -0.3982 17.7750
85.9298 -0.3011 17.7750
85.1806 -0.1637 17.7750
84.9250 -0.0000 17.7750
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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85.9298 -0.3011 17.7750
87.1217 -0.3982 17.7750
88.6750 -0.4456 17.7750
90.4839 -0.4425 17.7750
92.4250 -0.3971 17.7750
94.3420 -0.3280 17.7829
96.1519 -0.3915 17.7831
97.7070 -0.4342 17.7828
98.9009 -0.4595 17.7825
99.6517 -0.4716 17.7821
99.9086 -0.465 17.7820
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
100.657 -0.461 20.0608
100.4305 -0.4177 20.0601
99.7645 -0.3173 20.0579
98.7045 -0.1629 20.0547
97.3224 -0.0295 20.0507
95.1090 -0.3144 20.0540
93.9469 -0.3562 20.0540
92.2057 -0.3969 20.0540
90.5832 -0.3997 20.0540
89.1899 -0.3572 20.0540

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88.1208 0.2701 20.0540
87.4487 0.1469 20.0540
87.2195 0.0000 20.0540
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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89.1899 -0.3572 20.0540
90.5832 -0.3997 20.0540
92.2057 -0.3969 20.0540
93.9469 -0.3562 20.0540
95.6638 -0.3372 20.0621
97.2872 -0.3942 20.0622
98.6821 -0.4325 20.0620
99.7530 -0.4552 20.0617
100.4265 -0.4660 20.0614
100.657 -0.461 20.0613
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
101.3318 -0.447 22.1171
101.1288 -0.4092 22.1164
100.5318 -0.3191 22.1145
99.5816 -0.1808 22.1116
98.3427 -0.0083 22.1080
96.8990 0.1815 22.1041
95.9413 0.2981 22.1099
93.7590 0.3558 22.1099
92.3046 0.3583 22.1099
91.0556 0.3202 22.1099
90.0972 0.2421 22.1099
89.4948 0.1317 22.1099
89.2893 0.0000 22.1099
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
89.4948 -0.1317 22.1099
90.0972 -0.2421 22.1099
91.0556 -0.3202 22.1099
92.3046 -0.3583 22.1099
93.7590 -0.3558 22.1099
95.9413 -0.2981 22.1099
96.8559 -0.3370 22.1183
98.3111 -0.3881 22.1184
99.5615 -0.4224 22.1182
100.5215 -0.4427 22.1179
101.1252 -0.4524 22.1176
101.3318 -0.447 22.1175
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
101.869 -0.432 23.7484
101.6846 -0.3967 23.7478
101.1423 -0.3149 23.7461
100.2793 -0.1893 23.7434
99.1540 -0.0326 23.7402
97.8427 0.1397 23.7366
96.6709 0.2815 23.7415
94.9917 0.3232 23.7415
93.6707 0.3255 23.7415
92.5363 0.2908 23.7415
91.6658 0.2199 23.7415
91.1186 0.1196 23.7415
90.9320 0.0000 23.7415
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
91.1186 -0.1196 23.7415
91.6658 -0.2199 23.7415
92.5363 -0.2908 23.7415
93.6707 -0.3255 23.7415
94.9917 -0.3232 23.7415
96.6709 -0.2815 23.7415
97.8035 -0.3312 23.7495
99.1253 -0.3776 23.7496

100.2610 -0.4088 23.7494
101.1330 -0.4272 23.7492
101.6813 -0.4360 23.7489
101.869 -0.432 23.7488
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
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102.214 -0.419 24.7958
102.0415 -0.3861 24.7952
101.5344 -0.3096 24.7936
100.7273 -0.1920 24.7911
99.6750 -0.0456 24.7881
98.4487 0.1156 24.7848
97.1716 0.2692 24.7890
95.7832 0.3022 24.7890
94.5478 0.3044 24.7890
93.4869 0.2720 24.7890
92.6729 0.2057 24.7890
92.1611 0.1118 24.7890
91.9866 0.0000 24.7890
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
92.1611 -0.1118 24.7890
92.6729 -0.2057 24.7890
93.4869 -0.2720 24.7890
94.5478 -0.3044 24.7890
95.7832 -0.3022 24.7890
97.1716 -0.2692 24.7890
98.4121 -0.3248 24.7968
99.6481 -0.3681 24.7969
100.7103 -0.3973 24.7967
101.5257 -0.4146 24.7965
102.0385 -0.4228 24.7962
102.214 -0.419 24.7961
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
102.3341 -0.413 25.1563
102.1658 -0.3820 25.1557
101.6708 -0.3073 25.1541
100.8830 -0.1926 25.1517
99.8558 -0.0496 25.1487
98.6588 0.1077 25.1455
97.3500 0.2647 25.1500
96.0559 0.2950 25.1500
94.8500 0.2971 25.1500
93.8145 0.2655 25.1500
93.0199 0.2007 25.1500
92.5204 0.1092 25.1500
92.3500 0.0000 25.1500
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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93.0199 -0.2007 25.1500
93.8145 -0.2655 25.1500
94.8500 -0.2971 25.1500
96.0559 -0.2950 25.1500
97.3293 -0.2638 25.1568
98.6210 -0.3221 25.1572
99.8296 -0.3645 25.1573
100.8663 -0.3930 25.1572
101.6623 -0.4098 25.1569
102.1628 -0.4178 25.1567
102.3341 -0.413 25.1566
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

&PATCH1 IRV=0, IDPAT=2, MAKE=0, KCOMP=1, KASS=1, IPATSYM=1, IPATCOP=0, &END
FOG UAV BOOM (10x12) CLOSED ENDS
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
53.5000 0.0000 9.3750

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86.8998 0.2785 8.5455
86.8998 0.5195 8.6711
86.8998 0.7046 8.8564
86.8998 0.8296 9.0971
86.8998 0.8750 9.3739
86.8998 0.8290 9.6548
86.8998 0.7031 9.8956
86.8998 0.5175 10.0804
86.8998 0.2766 10.2051
86.8998 0.0000 10.2500
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
88.5002 0.0000 8.5178
88.5002 0.2731 8.5625
88.5002 0.5094 8.6857
88.5002 0.6900 8.8665
88.5002 0.8127 9.1024
88.5002 0.8572 9.3738
88.5002 0.8121 9.6495
88.5002 0.6885 9.8855
88.5002 0.5074 10.0658
88.5002 0.2712 10.1882
88.5002 0.0000 10.2322
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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88.5000 0.0000 9.3750
88.5000 0.0000 9.3750
88.5000 0.0000 9.3750
88.5000 0.0000 9.3750
88.5000 0.0000 9.3750
88.5000 0.0000 9.3750
88.5000 0.0000 9.3750
88.5000 0.0000 9.3750
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END

&PATCH1 IREV=0, IDPAT=1, MAKE=0, KCOMP=1, KASS=1, IPATSYN=0, IPATCOP=0, &END
&VERT STAB 0 DEG / NO DEFLECTION (10X12)
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
97.5000 0.0 10.4000
97.1593 0.0360 10.4000
96.1603 0.1029 10.4000
94.5711 0.2011 10.4000
92.5000 0.3161 10.4000
90.0882 0.4315 10.4000
87.5000 0.5294 10.4000
84.9118 0.5900 10.4000
82.5000 0.5942 10.4000
80.4289 0.5310 10.4000
78.8397 0.4015 10.4000
77.8407 0.2183 10.4000
77.5000 0.0000 10.4000
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
77.8407 -0.2183 10.4000
78.8397 -0.4015 10.4000
80.4289 -0.5310 10.4000
82.5000 -0.5942 10.4000
84.9118 -0.5900 10.4000
87.5000 -0.5294 10.4000
90.0882 -0.4315 10.4000
92.5000 -0.3161 10.4000
94.5711 -0.2011 10.4000
96.1603 -0.1029 10.4000
97.1593 -0.0360 10.4000

97.5000 0.0 10.4000
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
97.5000 0.0 10.4000
97.6187 0.0356 10.7610
97.2821 0.0356 10.7610
96.2953 0.1016 10.7610
94.7256 0.1987 10.7610
92.5590 0.3185 10.7610
90.2976 0.4262 10.7610
87.7410 0.5229 10.7610
85.1845 0.5828 10.7610
82.8022 0.5869 10.7610
80.7565 0.5245 10.7610
79.1868 0.3966 10.7610
78.2000 0.2157 10.7610
77.8634 0.0000 10.7610
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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79.1868 -0.3966 10.7610
80.7565 -0.5245 10.7610
82.8022 -0.5869 10.7610
85.1845 -0.5828 10.7610
87.7410 -0.5229 10.7610
90.2976 -0.4262 10.7610
92.6799 -0.3122 10.7610
94.7256 -0.1987 10.7610
96.2953 -0.1016 10.7610
97.2821 -0.0356 10.7610
97.6187 0.0 10.7610
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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97.9631 0.0 11.8085
97.6387 0.0343 11.8085
96.6874 0.0980 11.8085
95.1740 0.1915 11.8085
92.7472 0.3243 11.8085
90.9052 0.4109 11.8085
88.4406 0.5041 11.8085
85.9760 0.5618 11.8085
83.6793 0.5658 11.8085
81.7071 0.5056 11.8085
80.1938 0.3823 11.8085
79.2425 0.2079 11.8085
78.9180 0.0000 11.8085
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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80.1938 -0.3823 11.8085
81.7071 -0.5056 11.8085
83.6793 -0.5658 11.8085
85.9760 -0.5618 11.8085
88.4406 -0.5041 11.8085
90.9052 -0.4109 11.8085
93.2019 -0.3010 11.8085
95.1740 -0.1915 11.8085
96.6874 -0.0980 11.8085
97.6387 -0.0343 11.8085
97.9631 0.0 11.8085
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98.4996 0.0 13.4401
98.1940 0.0323 13.4401
97.2979 0.0923 13.4401
95.8725 0.1804 13.4401
93.0906 0.3301 13.4401
91.8516 0.3871 13.4401
89.5302 0.4748 13.4401
87.2087 0.5292 13.4401

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85.0454 0.5330 13.4401
83.1878 0.4763 13.4401
81.7624 0.3601 13.4401
80.8663 0.1958 13.4401
80.5607 0.0000 13.4401
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
80.8663 -0.1958 13.4401
81.7624 -0.3601 13.4401
83.1878 -0.4763 13.4401
85.0454 -0.5330 13.4401
87.2087 -0.5292 13.4401
89.5302 -0.4748 13.4401
91.8516 -0.3871 13.4401
94.0149 -0.2835 13.4401
95.8725 -0.1804 13.4401
97.2379 -0.0923 13.4401
98.1940 -0.0323 13.4401
98.4996 0.0 13.4401
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
99.1756 0.0 15.4960
98.8938 0.0298 15.4960
98.0673 0.0851 15.4960
96.7527 0.1664 15.4960
95.0394 0.2615 15.4960
93.6103 0.3318 15.4960
90.9031 0.4380 15.4960
88.7620 0.4881 15.4960
86.7668 0.4916 15.4960
85.0535 0.4393 15.4960
83.7389 0.3321 15.4960
82.9124 0.1806 15.4960
82.6305 0.0000 15.4960
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
82.9124 -0.1806 15.4960
83.7389 -0.3321 15.4960
85.0535 -0.4393 15.4960
86.7668 -0.4916 15.4960
88.7620 -0.4881 15.4960
90.9031 -0.4380 15.4960
93.6103 -0.3318 15.4960
95.0394 -0.2615 15.4960
96.7527 -0.1664 15.4960
98.0673 -0.0851 15.4960
98.8938 -0.0298 15.4960
99.1756 0.0 15.4960
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
99.9250 0.00 17.7750
99.6694 0.0270 17.7750
98.9202 0.0772 17.7750
97.7283 0.1509 17.7750
96.1750 0.2371 17.7750
94.3000 0.3265 17.7750
92.4250 0.3971 17.7750
90.4839 0.4425 17.7750
88.6750 0.4456 17.7750
87.1217 0.3982 17.7750
85.9298 0.1011 17.7750
85.1806 0.1637 17.7750
84.9250 0.0000 17.7750
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
85.1806 -0.1637 17.7750
85.9298 -0.1011 17.7750
87.1217 -0.3982 17.7750
88.6750 -0.4456 17.7750
90.4839 -0.4425 17.7750
92.4250 -0.3971 17.7750

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94.3661 0.3236 17.7750
96.1750 -0.2371 17.7750
97.7283 -0.1509 17.7750
98.9202 -0.0772 17.7750
99.6694 -0.0270 17.7750
99.9250 0.00 17.7750
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
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TNODES=0, TNPS=0, TINTS=0, &END
100.6744 0.00 20.0540
100.4451 0.0242 20.0540
99.7731 0.0692 20.0540
98.7039 0.1353 20.0540
97.3106 0.2126 20.0540
95.1090 0.3144 20.0540
93.9469 0.3562 20.0540
92.2057 0.3969 20.0540
90.5832 0.3997 20.0540
89.1899 0.3572 20.0540
88.1208 0.2701 20.0540
87.4487 0.1469 20.0540
87.2195 0.0000 20.0540
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
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88.1208 -0.2701 20.0540
89.1899 -0.3572 20.0540
90.5832 -0.3997 20.0540
92.2057 -0.3969 20.0540
93.9469 -0.3562 20.0540
95.1090 -0.2903 20.0540
97.3106 -0.2126 20.0540
98.7039 -0.1353 20.0540
99.7731 -0.0692 20.0540
100.4451 -0.0242 20.0540
100.6744 0.00 20.0540
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
101.3504 0.00 22.1099
101.1449 0.0217 22.1099
100.5424 0.0620 22.1099
99.5841 0.1213 22.1099
98.3351 0.1906 22.1099
96.8807 0.2602 22.1099
95.9413 0.2981 22.1099
93.7590 0.3558 22.1099
92.3046 0.3583 22.1099
91.0556 0.3202 22.1099
90.0972 0.2421 22.1099
89.4948 0.1317 22.1099
89.2893 0.0000 22.1099
&BPNODE TNODE=1, TNPC=0, TINTC=0, &END
89.4948 -0.1317 22.1099
90.0972 -0.2421 22.1099
91.0556 -0.3202 22.1099
92.3046 -0.3583 22.1099
93.7590 -0.3558 22.1099
95.9413 -0.2981 22.1099
96.8807 -0.2602 22.1099
98.3351 -0.1906 22.1099
99.5841 -0.1213 22.1099
100.5424 -0.0620 22.1099
101.1449 -0.0217 22.1099
101.3504 0.00 22.1099
&BPNODE TNODE=3, TNPC=0, TINTC=0, &END
&SECT1 STX=0.0, STY=0.0, STZ=0.0, SCALE=1.0, ALF=0.0, THETA=0.0, INMODE=4,
TNODES=0, TNPS=0, TINTS=0, &END
101.8869 0.00 23.7415
101.7002 0.0197 23.7415
101.1530 0.0564 23.7415

```



```

&BLPARAM RN = 929000, VISC = 0.022641, NSLBL = 1,
&END

&VS1 NVOLR= 0, NVOLC= 0,
&VS2 X0= -0.1000, Y0= 1.5000, Z0= -0.1000, INTVSR= 1,
&VS3 X1= -0.1000, Y1= 1.5000, Z1= 0.1000, NPT1= 0,
&VS4 X2= -0.1000, Y2= 1.5000, Z2= 0.1000, NPT2= 20,
&VS5 X3= 1.1000, Y3= 1.5000, Z3= -0.1000, NPT3= 25,
&END

&VS6 XR0= 2.0000, YR0= 2.0000, ZR0= 0.0000, INTVSC= 1,
&VS7 XR1= 4.0000, YR1= 2.0000, ZR1= 0.0000,
&VS8 R1= 2.0000, YR2= 2.0000, ZR2= 1.0000,
&VS9 NRAD= 5, NPHI= 12, NLEN= 3, PH12= 360.0,
&END

&SLIN1 NSTLIN= 4,
&SLIN2 SX0= -6.5000, SY0= 2.50000, SZ0= 7.5000,
SU= 2.0000, SD= 0.100, INTSL= 1,
&SLIN2 SX0= -8.25000, SY0= 0.00000, SZ0= 7.5000,
SU= 2.0000, SD= 0.100, INTSL= 1,
&END

&SLIN2 SX0= -6.5000, SY0= 2.50000, SZ0= 7.5000,
SU= 15.0000, SD= 100.0000, DS= 0.500, INTSL= 1,
&SLIN2 SX0= -8.25000, SY0= 0.00000, SZ0= 7.5000,
SU= 15.0000, SD= 100.0000, DS= 0.500, INTSL= 1,
&END

```

## **APPENDIX D**

### **MATLAB SCRIPT FOR DYNAMIC MODE ANALYSIS**



```

% froguav.m: This MATLAB script calculates FROG UAV dynamics. Eigenvalue modal analysis
% and response to control input is obtained for three aerodynamic models.
%
clear

% Calculate trim lift and drag coefficients

% FROG Trim condition

W = 67.73; % lbs
m = W/32.2; % slugs
S = 2530/144; % ft^2, 2530 in^2
V = 88; % ft/s = 1056 in/s
M = V/1118; % trim mach number
cbar = 20/12; % ft = 20 in
b = 126.5/12; % ft = 124 in
rho = 0.002327; % slugs/ft^3 800 ft MSL std day
cruise_HP = 5;
etaP = 0.35;
L_D=7;
CL0 = 0.4295;
Ixx = 12.52; Iyy = 8.43; Izz = 18.55; Ixz=0; %slugs-ft^2
q = 0.5*rho*(V)^2;
CL = W/(q*S);

% Input the non-dimensional stab derivatives:

% *****
for i = 1:3

    if i==1

        source='CMARC'

        % Longitudinal Stability Derivatives
        D_L_D=W/L_D;CD_L_D = D_L_D/(q*S); % Drag from Lift to Drag Ratio
        Tr=cruise_HP*etaP*550/V; CD_Tr=Tr/(q*S); % Drag from thrust required calculation
        CD=(CD_L_D +CD_Tr)/2; % CD averaged from both methods
        CLalpha = 4.845; CDalpha = 0.2664; CMalpha = -0.4126;
        CLalphadot = 1.420; CMalphadot = -6.264; CDalphadot = 0; % Assumed to be small
        alphas0 = 0; % radians
        theta0 = alphas0;
        CLmach = 0; CDMach = 0; CMmach = 0;
        CLq = 6.82; CMq = -11.78; CDq = 0; % Assumed to be small
        CLde = 0.4378; CMde = -1.199; CDde = 0.0092; % Induced drag contribution only

        % Lateral - Directional Stability Derivatives

        CYbeta = -0.2493; Clbeta = -0.0630; Cnbeta = 0.0630;
        Clp = -0.4514; Cnp = -0.0220; CYp = 0.0488;
        Clr = 0.1210; Cnr = -0.1210; CYr = 0.3370;
        Cldr = 0.0040; Cndr = -0.0453; CYdr = 0.0928;
        Clde = 0.1943; Cnde = -0.0121; CYde = -0.0206;

    elseif i==2

        source='Classical_Analysis'

        % Longitudinal Stability Derivatives
        D_L_D=W/L_D;CD_L_D = D_L_D/(q*S); % Drag from Lift to Drag Ratio
        Tr=cruise_HP*etaP*550/V; CD_Tr=Tr/(q*S); % Drag from thrust required calculation
        CD=(CD_L_D +CD_Tr)/2; % CD averaged from both methods

        CLalpha = 4.82; CDalpha = 0.253; CMalpha = -0.70 % d_epsilon/d_alpha = 0.40

        CLalphadot = 1.56; CMalphadot = -4.14; CDalphadot = 0; % Assumed to be small
        alphas0 = 0; % radians
        theta0 = alphas0;
        CLmach = 0; CDMach = 0; CMmach = 0;
        CLq = 3.89; CMq = -11.39; CDq = 0; % Assumed to be small
        CLde = 0.39; CMde = -1.04; CDde = 0.00;
    end
end

```

```

% Lateral - Directional Stability Derivatives

CYbeta = -0.511; Clbeta = -0.055; Cnbeta = 0.051;
Clp = -0.300; Cnp = -0.072; Cyp = 0; % Assumed to be small
Clr = 0.168; Cnr = -0.0762; CYr = 0.140;
Cldr = 0.0056; Cndr = -0.0341; CYdr = 0.081;
Clda = 0.213; Cnda = -0.0236; CYda = -0.00;

else

    source='Parameter_Analysis'

% Longitudinal Stability Derivatives
CL = 0.4295; CD = 0.0614;
CLalpha = 4.0907; CDalpha = 0.23; CMalpha = -0.4174;
CLalphadot = 1.3877; CMalphadot = -3.7115; CDalphadot = 0; % Assumed to be small
alphatrim = 0; % radians
theta0 = alphatrim;
CLmach = 0; CDmach = 0; CMmach = 0;
CLq = 3.35; CMq = -8.8818; CDq = 0; % Assumed to be small
CLde = 1.1249; CMde = -1.6208; CDde = 0.0676;

% Lateral - Directional Stability Derivatives
CYbeta = -0.9867; Clbeta = -0.0942; Cnbeta = 0.1755;
Clp = -0.4483; Cnp = -0.1077; Cyp = 0; % Assumed to be small
Clr = 0.2078; Cnr = -0.1212; CYr = 0.1096;
Cldr = 0.0004; Cndr = -0.0785; CYdr = 0.0926;
Clda = 0.2387; Cnda = -0.0261; CYda = 0;

end

% Calculate the Dimensional Stability Derivatives

Xu = -q*S/(m*V)*(2*CD+M*CDmach); % Xu - 1/sec , assumes dCD/dM=0 (ie no Mach effect)
Xalpha = q*S/m*(CL-CDalpha); % Xalpha - ft/sec^2
Xalphadot = -q*S/m*cbar/(2*V)*CDalphadot; % Xalphadot - ft/sec
Xq = -q*S/m*cbar/(2*V)*CDq; % Xq - ft/sec
Xde = -q*S/m*CDde; % Xde - ft/sec^2

Zu = -q*S/(m*V)*(2*CL+M*CLmach); % Zu - 1/sec , assumes dCL/dM=0 (ie no Mach effect)
Zalpha = -q*S/m*(CD+CLalpha); % Zalpha - ft/sec^2
Zalphadot = -q*S/m*cbar/(2*V)*CLalphadot; % Zalphadot - ft/sec
Zq = -q*S/m*cbar/(2*V)*CLq; % Zq - ft/sec
Zde = -q*S/m*CLde; % Zde - ft/sec^2

Mu = q*S*cbar/(Iyy*V)*CMmach; % Mu - ft/sec
Malpha = q*S*cbar/Iyy*CMalpha; % Malpha - 1/sec^2
Malphadot = q*S*cbar/Iyy*cbar/(2*V)*CMalphadot; % Malphadot - 1/sec
Mq = q*S*cbar/Iyy*cbar/(2*V)*CMq; % Mq - 1/sec
Mde = q*S*cbar/Iyy*CMde; % Mde - 1/sec^2

% Linearized Longitudinal 4x4 Plant Matrix

% Form the An Bn and In plant matrices

An = [V*Xu Xalpha 0 -32.17*cos(theta0); V*Zu Zalpha (V+Zq) -32.17*sin(theta0);
V*Mu Malpha Mq 0; 0 0 1 0];
Bn = [Xde Zde Mde 0]';
In = [V 0 0 0; 0 (V-Zalphadot) 0 0; 0 -Malphadot 1 0; 0 0 0 1];

A = inv(In)*An;
B = inv(In)*Bn;

% Find Short and Long Period Natural Frequency and damping

out=source
out='Longitudinal mode E-values'
P = poly(A);

```

```

R = roots(P)
out='Short Period'
phi = angle(R);
Z1(i) = (1/(1+tan(phi(1))^2))^0.5
Wn1(i) = real(R(1))/(-Z1(i))
Wd1(i) = (1-Z1(i)^2)^0.5*Wn1(i);
Td1(i) = 2*pi/Wd1(i);

out='Long Period'

Z3(i) = (1/(1+tan(phi(3))^2))^0.5
Wn3(i) = real(R(3))/(-Z3(i))
Wd3(i) = (1-Z3(i)^2)^0.5*Wn3(i);
Td3(i) = 2*pi/Wd3(i);

out='Step response'

C1=[1 0 0 0;0 1 0 0;0 0 1 0; 0 0 0 1]; D1=0;
U=zeros(1001,1);
U(101:1001)=-2/57.3;
t=(0:.01:10);
SYS=ss(A,B,C1,D1);
[Y,T]=lsim(SYS,U,t);
tl=t;
de_s=U*57.3;
alpha_s(:,i)=Y(:,2)*57.3;
pr_s(:,i)=Y(:,3)*57.3;
theta_s(:,i)=Y(:,4)*57.3;

C1=[1 0 0 0;0 1 0 0;0 0 1 0; 0 0 0 1]; D1=0;
U=zeros(1001,1);
U(101:160)=-5/57.3;
U(161:220)=5/57.3;
t=(0:.01:10);
SYS=ss(A,B,C1,D1);
[Y,T]=lsim(SYS,U,t);
tl=t;
de_d=U*57.3;
alpha_d(:,i)=Y(:,2)*57.3;
pr_d(:,i)=Y(:,3)*57.3;
theta_d(:,i)=Y(:,4)*57.3;

% Lateral-Directional 4x4 Plant Matrix

% Calculate the Dimensional Stability Derivatives

Ybeta = q*S/m*(CYbeta); % Ybeta - ft/sec^2
Yp = q*S/m*b/(2*V)*CYp; % Yp - ft/sec
Yr = q*S/m*b/(2*V)*CYr; % Yr - ft/sec
Yda = q*S/m*CYda; % Yda - ft/sec^2
Ydr = q*S/m*CYdr; % Ydr - ft/sec^2

Lbeta = q*S*b/Ixx*(Clbeta); % Lbeta - 1/sec^2
Lp = q*S*b/Ixx*b/(2*V)*Clp; % Lp - 1/sec
Lr = q*S*b/Ixx*b/(2*V)*Clr; % Lr - 1/sec
Lda = q*S*b/Ixx*Cllda; % Lda - 1/sec^2
Ldr = q*S*b/Ixx*Clldr; % Ldr - 1/sec^2

Nbeta = q*S*b/Izz*(Cnbeta); % Nbeta - 1/sec^2
Np = q*S*b/Izz*b/(2*V)*Cnp; % Np - 1/sec
Nr = q*S*b/Izz*b/(2*V)*Cnr; % Nr - 1/sec
Nda = q*S*b/Izz*Cnda; % Nda - 1/sec^2
Ndr = q*S*b/Izz*Cndr; % Ndr - 1/sec^2

% Linearized Longitudinal 4x4 Plant Matrix

source

```

```

longmodes='Lateral Directional 4x4 Plant Matrix'

% Form the An Bn and In plant matrices

Cn = [Ybeta Yp 32.17*cos(theta0) (Yr-V); Lbeta Lp 0 Lr; 0 1 0 0; Nbeta Np 0 Nr];
Dn = [Yda Lda 0 Nda; Ydr Ldr 0 Ndr]';
IIn = [V 0 0 0; 0 1 0 -Ixz/Ixx; 0 0 1 0; 0 -Ixz/Izz 0 1];

C = inv(IIn)*Cn;
D = inv(IIn)*Dn;

% Find Dutch roll, roll and spiral Natural Frequency and damping

out='Lateral Directional mode E-values'

P1 = poly(C);

R1 = roots(P1)

if i==1

    out='Dutch Roll Mode'

    phi = angle(R1);
    Z2(i) = (1/(1+tan(phi(2))^2))^0.5
    Wn2(i) = real(R1(2))/(-Z2(i))
    Wd2(i) = (1-Z2(i)^2)^0.5*Wn2(i);
    Td2(i) = 2*pi/Wd2(i);

    out='Roll Mode'
    roll(i) = (R1(1))
    out='Spiral Mode'
    Spiral(i) = (R1(4));

elseif i==2

    out='Dutch Roll Mode'

    phi = angle(R1);
    Z2(i) = (1/(1+tan(phi(1))^2))^0.5
    Wn2(i) = real(R1(1))/(-Z2(i))
    Wd2(i) = (1-Z2(i)^2)^0.5*Wn2(i);
    Td2(i) = 2*pi/Wd2(i);
    out='Roll Mode'
    roll(i) = (R1(3))
    out='Spiral Mode'
    Spiral(i) = (R1(4));

else

    out='Dutch Roll Mode'
    phi = angle(R1);
    Z2(i) = (1/(1+tan(phi(1))^2))^0.5
    Wn2(i) = real(R1(1))/(-Z2(i))
    Wd2(i) = (1-Z2(i)^2)^0.5*Wn2(i);
    Td2(i) = 2*pi/Wd2(i);
    out='Roll Mode'
    roll(i) = (R1(3))
    out='Spiral Mode'
    Spiral(i) = (R1(4))

end

% Aileron step

C1=[1 0 0 0;0 1 0 0;0 0 1 0; 0 0 0 1]; D1=0;
U=zeros(1001,2);
U(101:1001,1)=2/57.3;
t=(0:.01:10);
SYS=ss(C,D,C1,D1);
[Y,T]=lsim(SYS,U,t);

```

```

tld=t;
da_sa=U*57.3;
rr_sa(:,i)=Y(:,2)*57.3;
phi_sa(:,i)=Y(:,3)*57.3;
beta_sa(:,i)=Y(:,1)*57.3;

% Aileron doublet

C1=[1 0 0 0;0 1 0 0;0 0 1 0; 0 0 0 1]; D1=0;
U=zeros(1001,2);
U(101:175,1)=-5/57.3;
U(176:250,1)=5/57.3;
t=(0:.01:10);
SYS=ss(C,D,C1,D1);
[Y,T]=lsim(SYS,U,t);
tld=t;
da_da=U*57.3;
rr_da(:,i)=Y(:,2)*57.3;
phi_da(:,i)=Y(:,3)*57.3;
beta_da(:,i)=Y(:,1)*57.3;

% Rudder step

C1=[1 0 0 0;0 1 0 0;0 0 1 0; 0 0 0 1]; D1=0;
U=zeros(101,2);
U(101:1001,2)=2/57.3;
t=(0:.01:10);
SYS=ss(C,D,C1,D1);
[Y,T]=lsim(SYS,U,t);
tld=t;
dr_sr=U*57.3;
beta_sr(:,i)=Y(:,1)*57.3;
lr_sr(:,i)=Y(:,2)*57.3;
rr_sr(:,i)=Y(:,4)*57.3;

% Rudder doublet

C1=[1 0 0 0;0 1 0 0;0 0 1 0; 0 0 0 1]; D1=0;
U=zeros(1001,2);
U(101:175,2)=-5/57.3;
U(176:250,2)=5/57.3;
t=(0:.01:10);
SYS=ss(C,D,C1,D1);
[Y,T]=lsim(SYS,U,t);
tld=t;
dr_dr=U*57.3;
beta_dr(:,i)=Y(:,1)*57.3;
lr_dr(:,i)=Y(:,2)*57.3;
rr_dr(:,i)=Y(:,4)*57.3;

end
%*****
% Plot Responses
% Plot Elevator Step Response
figure
subplot(4,1,1), plot(tl,de_s),title('LONGITUDINAL RESPONSE TO A 2 DEGREE ELEVATOR STEP
INPUT'),ylabel('Elevator (deg)'),axis([0 5 -4 4]),grid
subplot(4,1,2), plot(tl,alpha_s(:,1),'-.',tl,alpha_s(:,2),'--',tl,alpha_s(:,3),'-'),ylabel('A.O.A
(deg)'),axis([0 5 -5 10]),grid
subplot(4,1,3), plot(tl,pr_s(:,1),'-.',tl,pr_s(:,2),'--',tl,pr_s(:,3),'-'),ylabel('q
(deg/s)'),axis([0 5 -20 20]),grid
subplot(4,1,4), plot(tl,theta_s(:,1),'-.',tl,theta_s(:,2),'--',tl,theta_s(:,3),'-'),ylabel('Theta
(deg)'),grid
xlabel('Time (sec)'),axis([0 5 -10 50]), pause,
legend('CMARC','Classical','Parameter Est','0)

% Plot Elevator Doublet Response
figure

```

```

    subplot(4,1,1), plot(tl,de_d),title('LONGITUDINAL RESPONSE TO A 5 DEGREE ELEVATOR
    DOUBLET'),ylabel('Elevator (deg)'),axis([0 5 -10 10]),grid
    subplot(4,1,2), plot(tl,alpha_d(:,1),'-.',tl,alpha_d(:,2),'--',tl,alpha_d(:,3),'-'),ylabel('A.O.A
    (deg)'),axis([0 5 -12 12]),grid
    subplot(4,1,3), plot(tl,pr_d(:,1),'-.',tl,pr_d(:,2),'--',tl,pr_d(:,3),'-'),ylabel('q
    (deg/s)'),axis([0 5 -60 50]),grid
    subplot(4,1,4), plot(tl,theta_d(:,1),'-.',tl,theta_d(:,2),'--',tl,theta_d(:,3),'-'),ylabel('Theta
    (deg)'),grid
    xlabel('Time (sec)'),axis([0 5 -10 30]),pause
    legend('CMARC','Classical','Parameter Est',0)

    % Plot Aileron Step Response
    figure
    subplot(4,1,1), plot(tld,da_sa(:,1)),title('LATERAL-DIRECTIONAL RESPONSE TO A 2 DEGREE AILERON
    STEP INPUT'),ylabel('Aileron (deg)'),axis([0 5 -4 4]),grid
    subplot(4,1,2), plot(tld,rr_sa(:,1),'-.',tld,rr_sa(:,2),'--',tld,rr_sa(:,3),'-'),ylabel('p
    (deg/s)'),axis([0 5 -10 25]),grid
    subplot(4,1,3), plot(tld,phi_sa(:,1),'-.',tld,phi_sa(:,2),'--',tld,phi_sa(:,3),'-'),ylabel('Bank
    Angle (deg)'),axis([0 5 -10 70]),grid
    subplot(4,1,4), plot(tld,beta_sa(:,1),'-.',tld,beta_sa(:,2),'--',tld,beta_sa(:,3),'-
    '),ylabel('Beta (deg)'),grid
    xlabel('Time (sec)'),axis([0 5 -5 10]), pause,
    legend('CMARC','Classical','Parameter Est',0)

    % Plot Aileron Doublet Response
    figure
    subplot(4,1,1), plot(tld,da_da(:,1)),title('LATERAL-DIRECTIONAL RESPONSE TO A 5 DEGREE AILERON
    DOUBLET'),ylabel('Aileron (deg)'),axis([0 8 -10 10]),grid
    subplot(4,1,2), plot(tld,rr_da(:,1),'-.',tld,rr_da(:,2),'--',tld,rr_da(:,3),'-'),ylabel('p
    (deg/s)'),axis([0 8 -50 60]),grid
    subplot(4,1,3), plot(tld,phi_da(:,1),'-.',tld,phi_da(:,2),'--',tld,phi_da(:,3),'-'),ylabel('Bank
    Angle (deg)'),axis([0 8 -30 10]),grid
    subplot(4,1,4), plot(tld,beta_da(:,1),'-.',tld,beta_da(:,2),'--',tld,beta_da(:,3),'-
    '),ylabel('Beta (deg)'),grid
    xlabel('Time (sec)'),axis([0 8 -10 15]), pause,
    legend('CMARC','Classical','Parameter Est',0)

    % Plot Rudder Step Response
    figure
    subplot(4,1,1), plot(tld,dr_sr(:,2)),title('LATERAL-DIRECTIONAL RESPONSE TO A 2 DEGREE RUDDER STEP
    INPUT'),ylabel('Rudder (deg)'),axis([0 8 -4 4]),grid
    subplot(4,1,2), plot(tld,beta_sr(:,1),'-.',tld,beta_sr(:,2),'--',tld,beta_sr(:,3),'-
    '),ylabel('Beta (deg)'),axis([0 8 -1 3]),grid
    subplot(4,1,3), plot(tld,rr_sr(:,1),'-.',tld,rr_sr(:,2),'--',tld,rr_sr(:,3),'-'),ylabel('r
    (deg/s)'),axis([0 8 -10 5]),grid
    subplot(4,1,4), plot(tld,lr_sr(:,1),'-.',tld,lr_sr(:,2),'--',tld,lr_sr(:,3),'-'),ylabel('p
    (deg/s)'),grid
    xlabel('Time (sec)'),axis([0 8 -5 10]), pause,
    legend('CMARC','Classical','Parameter Est',0)

    % Plot Rudder Doublet Response
    figure
    subplot(4,1,1), plot(tld,dr_dr(:,2)),title('LATERAL-DIRECTIONAL RESPONSE TO A 5 DEGREE RUDDER
    DOUBLET'),ylabel('Rudder (deg)'),axis([0 8 -10 10]),grid
    subplot(4,1,2), plot(tld,beta_dr(:,1),'-.',tld,beta_dr(:,2),'--',tld,beta_dr(:,3),'-
    '),ylabel('Beta (deg)'),axis([0 8 -10 10]),grid
    subplot(4,1,3), plot(tld,rr_dr(:,1),'-.',tld,rr_dr(:,2),'--',tld,rr_dr(:,3),'-'),ylabel('r
    (deg/s)'),axis([0 8 -30 30]),grid
    subplot(4,1,4), plot(tld,lr_dr(:,1),'-.',tld,lr_dr(:,2),'--',tld,lr_dr(:,3),'-'),ylabel('p
    (deg)'),grid
    xlabel('Time (sec)'),axis([0 8 -20 20]),pause,
    legend('CMARC','Classical','Parameter Est',0)

```

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